GLOBAL WARMING DATABASE

TECHNOLOGY OPTIONS IN POWER AND END-USE SECTORS USING FOSSIL FUELS

by

Kajoli Banerjee Krishnan

Tata Energy Research Institute
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Preface

This paper constitutes the work done towards developing a database on the technology options available to arrest the greenhouse effect and help in conservation of non-renewable energy sources in the power sector and its end-use with special focus on their relevance to the Indian scenario The sources include coal, oil, and natural gas This database is envisaged as a part of a larger database to document and disseminate information on factors relating to and affecting the process of global warming The aim is to build a structure that is comprehensive and yet flexible enough to be updated with the passage of time and to widen the knowledge and understanding on the subject

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Introduction

Increased anthropogenic emissions of CO_2 (carbon dioxide) in the present century have caused a steep rise of about 40% in its concentration than the near constant level of 250 ppm prior to the industrial revolution. If the present trend in the use of fossil fuel continues, the concentration of CO_2 in the atmosphere is expected to double by the middle of the next century

The earth's atmosphere is largely impervious to the short wavelength solar insolation However, the reflected long wavelength radiation from the surface of the earth falls in the absorption spectrum of a number of molecules like those of CO_2, water vapour, methane, ozone, and nitrous oxide that reside in the air. These molecules capture the outgoing radiation and keep the earth warm. This phenomenon is called the greenhouse effect The greenhouse effect has over several millinea helped the biosphere to retain heat and aid in the growth and sustenance of various life forms This was possible because of the relatively steady level of GHGs (greenhouse gases) in the air Any cyclical variation in the concentration of GHGs occured over a span of thousands of years; and so, on the whole, equilibrium conditions prevailed in the atmosphere–biosphere interactions

In the recent years, there has been a sharp rise in man-made emissions of GHGs, the principle component being that of CO_2 CO_2 is a GHG and is strongly suspected to cause an enhanced greenhouse effect. Climate forecasting models indicate a rise of 1 5–4 5 °C in the average global temperature if CO_2 level doubles to about 500 ppm The rise of temperature is expected to be higher at higher latitudes This rise in temperature can alter the global climate, cause the melting of polar ice caps, raise the sea level, destroy existing ecosystems, and affect humankind on the whole.

In order to avoid the situation arising out of a possible fall-out of global warming, it is best to act now and arrest the rapid emission of CO_2 and other GHGs which account for about 50% of the current greenhouse effect. Fossil fuel combustion is a major anthropogenic source of CO_2. The levels of CO_2 also go up due to deforestation, conversion into agricultural land, and a dwelling for the swelling world population Fossil fuel burning produces NO_x (oxides of nitrogen) and SO_2 (sulphur dioxide), which cause acid rain and particulates that together destroy plant and animal life in forests. Inefficient burning of fossil fuel form a photochemical smog in the lower atmosphere in the form of ozone, which is a powerful GHG. Natural gas drilling, venting and transmission, and increased agricultural activity lead to higher concentrations of methane in the atmosphere. Use of CFCs (chlorofluorocarbons) in the form of refrigerants, aerosols, etc., has also added to the concentration of GHGs

It is important to conserve forests for their role in conserving life support systems—of soil and water—and in providing a sink for CO_2. At the same time, it is also important to minimize the CO_2 emissions. The present pace of industrial activity and living standards—specially in the north and among the affluent in the south—*development* has a meaning only with increasing overall and per capita rise in energy consumption, and it would take immense political will to control the demand and use of the main source of energy, i.e., fossil fuels. However, technological solutions could restrict the emissions of GHGs. This could be done by research and development activities to find efficient methods of generation and use of fossil fuel energy and an effective implementation of such technologies.

This study consists of a detailed database on technologies that generate power using fossil fuel and those that make use of this secondary energy. In Part I, the focus is on the power sector. Part II deals with end-use technologies—processes and devices. The database includes the description, status, cost, environmental performance, efficiency, conservation potential, applicability, and comments (wherever available) of these technologies with references. Each technology option is accompanied by a list of references for the benefit of readers.

PART I

Power sector

Coal-fired steam turbine

Description

In the pulverized coal combustion technology, coal is first crushed and finely ground to a very fine dust of approximately 75 micron in diameter This dust is then blown alongwith air into the boiler where it is burnt to produce heat The heat is absorbed by the water flowing through the tubes which line the boiler wall. The water is converted into high pressure steam which rotates a turbine to generate electricity. The low pressure steam from the turbine is transformed into water in a condenser and recycled to the boiler Coal ash, CO_2, SO_2, and NO_x which are produced due to combustion in the boiler, are carried up in a flue and discharged into the atmosphere Some of the ash settles down at the bottom and is removed by slurrying it with water [1]

Status

Coal-fired power plants are extremely common and exist in all parts of the world In 1988/89, 20 coal-fired thermal power stations were operational in India with a net generation of 138 875 GWh [2]

Cost

- Capital cost – $1300–1500/kW (includes solid handling and particulate control).
- Levelized annual cost – 4–5 cents/kWh.[3]
- Capital cost in India – Rs 25 000/kW at 1991/92 prices [4]
- Levelized annual cost – approx. 81 paisa/kWh at 1991/92 prices.[5]

Environmental performance (emissions in grams/kWh)[3]

CO_2 – 900–1000

SO_2 – 5–50 (proportional to coal–sulphur content normally 0.3–6%)

NO_x – 3–6 (proportional to coal–nitrogen content 0 5–2% and boiler/burner design)

Particulates – 1–5

Efficiency

There is a 30–37% efficient net thermal energy conversion [3]

Comments

A small amount of fuel oil is added to the coal-fired boiler for the start-up operation and fuel stabilization. This ranges from 5 to 40 ml/kWh of energy, the upper limit often being a result of inefficient maintenance and the use of old boilers in India.[6]

Some of the electricity generated in the coal-fired plant is used to power equipment like the coal-handling plant, coal-crushers, mills, and pumps. There are electrical losses associated with transformers and capacitors [1] Auxiliary consumption accounts for an average of about 10% of the electricity generated in India [5] Auxiliary consumption can be reduced by using: (i) efficient motor drives, (ii) proper co-ordination of motor characteristics; (iii) variable frequency drives; (iv) advanced boiler feed pumps;
(v) concrete volute pumps for sea water application; (vi) on-line cleaning of condensors, (vii) polishing of condensate; (viii) coal handling plant, (ix) mills and mill bay,
(x) electrostatic precipitator, (xi) ash-handling plants; (xii) improved instrumentation and control; (xiii) auxiliary switch gear; (xiv) better combustion control, and (xv) efficient lighting.[7]

Boiler efficiency is often much lower than the design efficiency [1] The boiler efficiency is limited to about 86% by the thermodynamic considerations of a coal-fired plant [6] Technological inputs, which can improve the efficiency of existing plants, include use of efficient boilers, regenerative turbines, ball mills, and the use of physically (and even chemically) treated coal Significant quantities of sulphur and ash content can be reduced if coal is washed before use and this improvement in the coal quality can lead to better boiler performance.[1]

Coal is cheap if environmental costs are left out, it is the most polluting of all fossil fuels Since the use of coal cannot be eliminated or even reduced significantly, there is a need to burn coal more cleanly Large fractions of SO_2, NO_x, and particulates can be removed from the flue gas using appropriate technologies Controlling CO_2 emission continues to be the most challenging task. Since the development of CO_2 scrubbing processes is in a nascent stage and in any case will be very expensive, there is an urgency to switch to commercially tested clean-coal technologies so that maximum energy can be produced out of a given unit of coal.

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4 Discussions with Mr I R Suri TERI

5 Discussions with Dr Ajay Mathur, TERI Calculated with the following inputs Cap Cost Rs 2 5 crores per MW, Annual O&M 2 5% of Cap Cost, Coal Cost Rs 300–400/t (tonne) Coal transport Rs 0 38 per tonne-km typically over 700 km heat content of coal 3500–4000 kcal/kg boiler eficiency 86% turbine requirement 2700 kcal per kWh auxillary requirements 10% of net generation conversion factor from energy to heat units 1 kWh of electric energy = 860 kcal of heat energy discounting rate 12% lifetime of boiler 20 years

6 Discussions with Dr Ajay Mathur

7 Auxiliary systems for conventional thermal stations M L Shishoo Urja 31 (4) April 1992 39–46

Oil-fired steam turbine

Description

Oil is atomized by an incoming stream of steam or air Since the fuel is often heavy oil, it is warmed to reduce the viscosity prior to its combustion in the boiler The hot combustion gases convert water into steam The steam runs the turbine to produce electricity Subsequently, the steam is condensed back to water and recycled to the boiler

Status

Oil-fired steam turbines are operational in developed countries There are no such plants in India [1]

Cost

- Capital cost – Two-thirds the cost of coal-fired plants [2]
- Cost of electricity generation – 2 76 cents/kWh [3]

Environmental performance (emissions in grams/kWh)[4]

CO_2 – 720–800

SO_2 – 3–30 (proportional to oil sulphur content normally 0 3–6%)

NO_x – 1 5–3.8 (proportional to oil nitrogen content and boiler/burner design)

Particulates – 0 2–2

Efficiency

There is a 30–37% efficient net thermal energy conversion [4]

Comments

Robert L San Martin[5] has reported that CO_2 emission from oil-fired plants is 725 metric tonnes/GWh of electricity, i.e., 725 g/kWh, which is within the range specified above. Oil-fired thermal plants have slightly different boiler and burner designs from those of coal based plants.[1] Auxiliary consumption in an oil-fired plant accounts for 3–4% of the electricity produced.[2]

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Gas-fired steam turbine

Description

Gas is combusted in the boiler The hot combustion gases convert the water running through the pipes lining the boiler wall into steam which runs a turbine The used steam is condensed back to water and recycled to the boiler

Status

Gas-fired steam turbines are employed in many countries, e g , USA and Germany [1 2] In India, some old coal-based thermal plants have been converted into gas-fired plants [3]

Cost

- Capital cost – $1200–1600/kW [4]
- Cost of electricity generation – 2 64 cents/kWh [5]

Environmental performance (emissions in grams/kWh)[4]

CO_2 – 500–550

SO_2 – less than 0.003

NO_x – 0 7–2 5

Particulates – less than 0 01

Efficiency

There is a 30–37% efficient net thermal energy conversion.[4]

Comments

The upper limit of boiler efficiency using gas is limited by thermodynamic considerations to 91% [3] Efficient conventional boilers have, (i) continuous control of water temperature and boiler heat output as a function of actual heat demand, (ii) enhanced heat exchangers and enhanced thermal insulation, and (iii) modulating boiler control [1]

Condensing boilers may be used to recover the heat of condensation contained in the water vapour formed during combustion. To recover the heat carried by the flue gas, heat exchangers are integrated within such boilers which can reduce the temperature of the flue gas to less than 40 °C [1] Heat of condensation can be recovered only if combustion is clean as in the case of natural gas. Condensing boilers use 15% less energy than modern high-efficiency boilers [1]

Natural gas is the cleanest fossil fuel Its principal constituent is methane whose molecule has one carbon atom for four hydrogen atoms and therefore, contributes the least amount of CO_2 per unit energy. Natural gas contains virtually no sulphur or sulphur compounds or particulate matter and its nitrogen content is much smaller compared to coal and oil. There exists a whole range of new technologies for the use of natural gas in the energy production sector. In addition to that, natural gas can be used in conjunction with coal in coal-fired plants to reduce emissions.[6] The combustion of natural gas is very efficient, since the gaseous fuel blends easily with combustion air thereby minimizing excess air that is responsible for cooling the flame temperature [1] At the present rate of consumption, the known worldwide reserves of natural gas are expected to last for another 60 years or so, hence, substitution of coal by gas does not promise to be a long-term solution to the energy development issue.[4] However, non-conventional sources of natural gas represent vast untapped reserves of energy These occur in the form of ice-like compounds called clathrates in which methane and other gases are trapped by water molecules Methane by itself is a GHG So there is need to develop ways by which there is minimum leakage of the gas during production and

transmission.[7] The present availability of natural gas in India is 17 mtoe (million tonnes of oil equivalent). Long-term projections on the basis of geological estimates indicate that gas availability will increase to 30 mtoe by the year 2000. So, in India there is ample scope for stepping up use of gas in the energy production sector.[2]

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Simple-cycle natural gas combustion turbine

Description

In simple-cycle combustion turbines, the fuel is burned in compressed air, and the combustion gases turn a turbine to generate electricity.[1]

Status

Simple-cycle natural gas combustion turbines are in use in the US [1 2] There are four operational simple-cycle gas turbines in India [3,4]

Cost

- Capital cost of a 510 MW plant in India – Rs 830 crores.
- Imported cost component – 50%

- Expected plant lifetime – 15 years.[5]
- Cost of electricity generation – 0.41 cents/kWh.[6]

Environmental performance (emissions in grams/kWh)

CO_2 – 555.13[1]

SO_2 – less than 0.003

NO_x – 2.0–3 0

Particulates – negligible[7]

Efficiency

There is about 30% thermal efficiency conversion [2]

Comments

Thermal efficiency of simple-cycle natural gas combustion turbines is comparable to that of a coal-fired plant. However, unlike the coal plants, they can be turned off quickly thereby making them useful for meeting peak demand requirements.[1]

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7 These can at best be indicative of the order of magnitude Calculated simply using inverse proportionality relationship between net efficiency and emission, efficiency values of simple and combined cycle gas plants, and emissions in case of combined cycle plants as given in the referenced text

Combined-cycle natural gas combustion turbine

Description

In a combined-cycle combustion turbine, the hot exhaust gases at around 450 °C from the combustion cycle of a simple-cycle combustion turbine are fed to a boiler where water is converted into steam, which is made to generate additional power by driving a steam turbine.[1,2]

Status

Natural gas combined-cycle plants are in operation in USA [1-3] There are three such plants operating in India.[4,5]

Cost

- Capital cost – \$551/kW for 120 MW unit (USA).
- Cost of electricity generation – 1.77 cents/kWh.[6]
- Capital cost of a 650 MW plant in India – Rs. 1650 crores
- Imported cost component – 55%
- Expected lifetime – 15 years [7]

Environmental performance (emissions in grams/kWh)[1]

CO_2 – 390–410

SO_2 – less than 0.002

NO_x – 1.4–1.8

Particulates – negligible

Efficiency

There is about 43–50% efficient thermal energy conversion.[1 3]

Comments

Both capital cost and efficiency are much higher for combined-cycle turbines compared to simple-cycle turbines So, these turbines are preferred for supplying base power [2] Combined-cycle systems have demonstrated high availability and reliability They also offer flexibility in utility planning and financing Because they are designed as pre-engineering modules, they can be in service for three years or less Phased installation permits initial generation from the gas turbine part of the facility in as little as 12–18 months. The capital cost of a combined-cycle system is less than half of a conventional coal-fired system.[3]

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7 Discussions with Ms Mala Damodaran, TERI

Steam injected gas turbine (STIG)

Description

The steam generated after the simple-cycle combustion operation and not required for process heat is injected back into the combustor for added power and efficiency The steam injection can also be performed with the integrated coal–gas turbine [1 2]

Status

This technology was commercialized in USA in the late eighties.[1] In India, HAL (Hindustan Aeronautics Limited) has been working, in collaboration with General Electric and Allison gas turbines, USA, on an industrial STIG programme.[3]

Cost

1. For steam injection in Integrated coal–gas turbine:
   - estimated installed capital cost – $1411/kW;
   - estimated busbar cost – 2.38 + 1.011 Pc* cents/kWh, and
   - plant cost – $1300/kW.[4]

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* Pc is the price of coal in $/GJ [2]

2. For steam injection in gas turbine:
   - plant cost – \$410/kW.[4]

Environmental performance (emmissions in grams/kWh)

1 For steam injection in integrated coal–gas turbine:
   - CO_2 – 1200;[5]
   - SO_2 – 99% reduction; and
   - NO_x – 0 09.[4]

2. For steam injection in Gas turbine:
   - CO_2– 600,[5] and
   - NO_x – 0 054.[4]

Efficiency

Net efficiency of convers efficiency of conversion in steam injectedion in steam injected integrated coal–gas turbine is 36% Net gas turbine is 40% [4]

Comments

A recent study showed that STIG was economically preferable to combined-cycle systems for installations of 50 MW or less [6] Overall, installation cost of the STIG plant will be at least 20% lower than the comparable combined cycle plant [3]

Steam injection has demonstrated several performance advantages over a simple-cycle gas turbine: (i) NO_x is reduced; (ii) gas-turbine efficiency is increased by 3–10%, (iii) power output of the gas-turbine is increased by 40–70%; [6] (iv) steam injection can be used to generate extra power required during peak load operation, and (v) the generated steam can partly substitute the natural gas fuel supply to the gas turbine during periods of reduced demand for electricity and steam and also in case the gas fuel supply is reduced for some reason [3]

A simple-cycle combustion turbine with a power output of 33 MW operating at an efficiency of 32% could produce an output of 51 MW at an increased efficiency of 40% with full steam injection.[1]

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5 Derived from estimated carbon emitted in [4] assuming complete conversion of carbon into CO_2 This is an approximation and sets an upper limit on CO_2 emission in the process

6 Changing prospects for natural gas in the United States W M Burnett and S D Ban, Science 244 (1989) 307–310

Inter-cooled steam injected gas turbine (ISTIG)

Description

In a steam injected gas turbine, the combustion air, which has to be compressed is cooled between the stages of compression, with some of the air channelled to the turbine blades Efficiency is gained because less power is required to compress cool air The diverted air lowers the temperature of the blades, enabling them to withstand higher gas temperature [1]

Status

This technology has been commercialized in USA [1]

Cost

1. For inter-cooled steam injection in integrated coal–gas turbine:
   - estimated installed capital cost – $1122/kW,
   - estimated busbar cost – 1 94 + 0 855 Pc* cents/kWh, and
   - plant cost – $1030/kW [1]

2 For inter-cooled steam injection in gas turbine·
   - plant cost – $400/kW [1]

Environmental performance (emmissions in grams/kWh)

1 For inter-cooled steam injection in integrated coal–gas turbine·
   - CO_2– 1000,[3]
   - SO_2 – 99% reduction; and
   - NO_x – 0.072.[1]

* Pc is the price of coal in $/GJ [2]

2. For inter-cooled steam injection in gas turbine:
- CO_2 – 500;[3] and
- NO_x – 0.036.[1]

Efficiency

Net efficiency of conversion in inter-cooled steam injected integrated coal–gas turbine is 42%. Net efficiency of conversion in inter-cooled steam injected gas turbine is 47%.[1]

Comments

ISTIG systems can be small and hence, suitable for use in both industries and utilities A proposed variation on the ISTIG involves pre-combustion catalytic reduction of natural gas with steam to yield CO (carbon monoxide) and hydrogen The chemical energy of the product will be greater than natural gas itself and subsequent ISTIG could yield an efficiency of more than 52%.[1]

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3 Derived from estimated carbon emitted in [1] assuming complete conversion of carbon into CO_2 This is an approximation and sets an upper limit on CO_2 emission in the process

Cofiring

Description

Cofiring natural gas in a coal-fired boiler involves the use of natural gas during start-up and normal boiler operations to provide a fraction of the boiler's total heat input and achieve a variety of boiler performance improvements due to use of gas.[1] Small amounts (1–10%) of natural gas can be introduced into the primary combustion furnace zone of a pulverized coal boiler in the cofiring process [2]

Status

Cofiring technology is in operation in USA.[1,2]

Cost

Incremental capital cost for cofiring 10% gas is $3/kW and total levelized cost in a 500 MW coal-fired plant retrofit is 0 13–0.14 cents/kWh.[1]

Environmental performance

Cofiring 10% natural gas in a high-sulphur coal boiler has been shown to reduce SO_2 emissions by 12%, nitrogen dioxide emissions by 25%, CO_2 emissions by 4%, and particulate emissions by 15% [1]

Efficiency

The boiler efficiency is between 86 and 91 depending on the fraction of natural gas in the fuel. Net efficiency is between 30 and 37%.

Comments

Other operational benefits of cofiring gas with coal include reduced erosion, slagging and/or fouling, reduced maintenance requirements, lower particulate loading and/or reduced mill load which can increase the unit's availability. The plant life can also be increased by the use of cofiring from a 30-year boiler life to 40–50 years. At 5 to 20% of input, the operational and emissions benefits of gas, compared to the full costs of coal, make cofiring a very viable and cost-effective technology (Delivered cost of coal can be on the average only half of that of natural gas on Btu equivalent basis, but this must be inflated by the incremental costs of inventory, storage, handling, and drying of coal which do not accrue to gas The implicit costs of ice, slag, and tube leaks also add to the price of coal alone.)[1]

Cofiring would be possible in India by changing the burner of a coal-fired plant [3]

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3 Discussion with Dr Ajay Mathur TERI

Gas-reburn technology

Description

Gas-reburn involves the injection of natural gas into the upper furnace above the primary region of combustion to produce a fuel-rich zone which improves combustion efficiency and reduces emissions. It typically uses at least 20% natural gas heat input over and above the heat-input for gas cofiring in the primary region of the boiler [1]

Status

Gas-reburn is in operation in USA.[1,2]

Cost

Incremental capital cost for gas-reburn technology is $12/kW and total levelized cost in a 500 MW coal-fired plant retrofit is 0 35–0.39 cents/kWh.[1]

Environmental performance

The reburning region converts 50–60% of NO_x to molecular nitrogen. Air is added above the reburn zone to complete combustion at a lower temperature (1200 °C) than in the primary furnace combustion zone, thereby minimizing the formation of NO_x in the secondary combustion zone.[2] The operation of gas-reburn using 20% gas with 80% coal has been shown to reduce SO_2 emissions by 20% and CO_2 emissions by 9% [1] Particulate and SO_2 emissions are reduced in proportion to the natural gas used [2]

Efficiency

The boiler efficiency is between 86 and 91 depending on the fraction of natural gas in the fuel Net efficiency is between 30 and 37%

Comments

Gas-reburn technology can easily be retrofitted to essentially all boiler designs at a first cost of 1–2% of the total cost of a new generating system. Although this technology has been proposed primarily for coal-fired plants, recent research indicates that it can be used in waste-fired boilers to help stabilize operations and destroy other harmful pollutants in the exhaust gas-stream and reduce the NO_x emissions [2]

References

1 Natural gas "Select-use" technologies Opportunities for emissions reduction using natural gas in conjunction with coal. Lee Solsbery, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12-14 1989, 377–395

2 Changing prospects for natural gas in the United States. W M Burnett and S D Ban Science 244 (1989), 307–310

Cogeneration

Description

Cogeneration is the generation of thermal and electric power at the site where both heat and power are needed. These facilities may be industrially or commercially owned.[1]

There are two basic types of cogeneration systems depending on whether electrical or thermal energy is produced first These are: (i) topping cycle cogeneration systems; and (ii) bottoming cycle cogeneration systems, respectively

In the topping cycle, the primary energy source is used to produce useful electrical or mechanical power Thermal energy that is exhausted from the turbine is captured and used for such purposes as industrial process heating, space heating or cooling, and water heating. Based on the prime mover used, the topping cycle systems could be steam turbine, gas turbine, combined steam/gas turbine, diesel engine, fuel cell, and Stirling engine topping cycle.[2]

The facilities can be equipped with internal combustion engines which drive generators for the production of electricity and feature heat exchangers for the recovery of heat from the engine exhaust and the engine cooling water to produce hot water for space heating Engines are normally fuelled by natural gas since its combustion does not produce any residue and enhances the engine life.[3] In back pressure turbines, the steam, instead of condensing in the turbine, is merely let down to a lower pressure and so retains a sufficiently high-grade heat to be used for industrial heating or space heating.[4] Highly efficient and low pollutant gas turbines rated 5 MW or less can be used as an alternative to internal combustion engines for cogeneration plants The high temperature of the turbine exhaust (500 °C) can be used to generate steam to run a steam-turbine The energy saving potential of such combined cycle plants is particularly high [3]

In the bottoming system, fuel is consumed to produce high temperature thermal energy needed in industrial application such as cement kilns, steel furnaces, or glass melting furnaces Subsequently heat is extracted from the hot exhaust steam and transferred to a fluid through a waste heat recovery boiler. The fluid is vaporized and the vapour is used to drive a turbine to produce electrical energy The Rankine cycle forms the basis of all bottoming systems and it uses steam or organic fluids

Status

Industrial cogeneration using back pressure turbines is standard practice in the process and other industries in industrialized countries. District heating systems are to be found in Germany, Denmark, the Netherlands, and in China.[4] In USA, electric power is

generated with the use of discharge heat recovered from the exhaust of water or space heating.[1] Steam, gas, combined turbines, and diesel engine topping cycle cogeneration systems are used in industries. Fuel cell and Stirling engine topping cycle and Organic Rankine cycle bottoming system are under development.[2] Industrial cogeneration facilities are available in India, e g., paper manufacture plants, petroleum refineries, and petrochemical complexes.[2]

Cost

Capital cost for combined output for industrial (140 kW) heat and power is $1000/kW [4] The economics of district heating systems is determined by the cost of heat transport and distribution system and the profile of heating demand, hence it is situation-specific [4]

Environmental performance

Emissions from cogeneration systems depend on the precise nature of the system, the fuel type, and quality. Gas turbine and combined cycle systems use fuel that emit negligible SO_2. Other specific emissions are reduced in proportion to the overall improvement in efficiency of cogeneration compared with a system in which heat and power are produced separately. Thermal discharges into the air are also reduced or eliminated [4]

Efficiency

Recovery and utilization of otherwise rejected heat increases overall fuel-use efficiency by 60–80% [1] The decentralized location of the cogeneration plant avoids transmission losses and saves as much as 40% of the energy input [3] Combined efficiency is 80–85%.[4]

Comments

Combined heat and power systems can also be developed for advanced technologies like IGCC (integrated coal gasification combined cycle) and FBC (fluidized bed combustion) since they too have fairly significant heat losses This will result in efficiencies exceeding 80% [5] For an effective use of cogeneration facilities, there is need to evolve a mechanism by which the usual power supply can provide a back-up in case of system failure and also accept the surplus power into the grid [4]

Steam turbine topping cycle system has a electricity to heat ratio of 28–70 kWh/GJ Gas turbine topping cycle systems can provide about 75% of the input fuel energy for process use Electricity to heat ratio is in the range of 130–215 kWh/GJ. Its

advantages are high availability, minimum environmental pollution, quick start up, small size, low weight, and low initial cost per kW. Sizes range from 50–100 MW. Sizes of diesel engine topping cycle range from a few kW to 40 MW. Typical fuel use effectiveness is 75% Electricity to heat ratio is 330–660 kWh/GJ. Electricity to heat ratio for a combined cycle system is 165–300 kWh/GJ.[2]

References

1 Changing prospects for natural gas in the United States, W M Burnett and S D Ban, Science 244 (1989). 307–310

2 Cogeneration systems evaluation model, S Anand and Virendra S Kothari, N Thangaraju, TERI, July 1989

3 Energy technologies for the use of natural gas to reduce CO_2 emissions including Gas reburn technology for coal firing. Roland Pfeiffer, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 361–375

4 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

5 The role of coal use and technology in the greenhouse effect, Irene M Smith, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 283–294

Cogeneration and STIG

Description

In a gas turbine cogeneration system, the hot exhaust gases after combustion are passed through a waste heat boiler to provide steam for heating. In a cogeneration system combined with STIG cycle, the steam not required for process use is injected back into the combustion chamber increasing mass flow and power output.[2]

Efficiency

Here 34–40% fuel energy is converted into electricity with full steam injection [2]

Comments

Combining cogeneration and STIG facilities provides the plant an ability to vary electrical versus thermal output to follow more closely the load requirements. The boiler output can provide steam for direct use in the facility or for injection into the turbine to increase the electrical output.[1] The system efficiency remains high over a wide range of steam/electricity ratios.[2]

References

1 Changing prospects for natural gas in the United States, W M Burnett and S D Ban, Science 244 (1989), 307–310

2 Improving the efficiency of electricity use in manufacturing, Marc Ross, Science, 244, April 1989 311–317

All purpose power generator

Description

All purpose power generator is a universal power-pack capable of providing a wide range of services It consists of a basic prime mover which could run on many different fuels including naturally available materials and methane gas. By using a specially designed, variable speed gear box, it is possible to greatly vary the output speed. When running at one of the lower speeds, it could drive a compressor to provide compressed air for pneumatic tools It could drive a hydraulic pump to provide power for lifting equipment and at very low speeds it could drive a water pump and be used for irrigation.[1]

Status

Lucas Electricals' workers have designed this universal power pack in UK.[1]

Comments

In considering the design, various bearing surfaces have been made much larger than normal and the components deliberately designed to last for about 20 years with almost no maintenance The instruction manual would enable the users to carry out the maintainance themselves and learn by doing it.[1]

Reference

1 Architect or bee? The human price of technology, Mike Cooley, Rev ed, Hogarth Press, London, 1987

Fuel-cells

Description

Fuel-cells employ an electrochemical process to generate power A flameless oxidation converts fuel energy to electricity The absence of a combustion process as in a conventional system makes the conversion step cleaner and more efficient [1]

Fuel-cells are usually named according to the type of electrolyte they use. The major types of fuel cell are: PAFC (phosphoric acid fuel-cell), MCFC (molten carbonate fuel cell), and SOFC (solid oxide fuel-cell). In MCFC, oxygen and CO_2 react with the available electrons at the cathode to form carbonate ions which move across the molten carbonate electrolyte to the anode to react with hydrogen and CO which is internally reformed from water and natural gas (methane). The electrons released in this process generate electricity. Water and CO_2 are the emissions from a fuel-cell. Each pair of electrodes can generate only up to 1 23 volts. So many pairs need to be stacked up for power-related applications.[1]

Status

The world's largest fuel-cell, a 11 MW PAFC, started generating power in a cogeneration facility in Japan in 1991. MCFCs are entering the demonstration phase of development in USA; SOFCs are still in the research and development phase.[1] Development work on fuel-cells is currently being undertaken in USA, Japan, the Netherlands, and Italy.[2]

Cost

- Capital cost of MCFC – \$1500/kW [1]
- Levelized annual cost – The present requirement for premium quality fuel implies that the fuel-cells are uneconomic compared with plants using cheaper fuels unless the premium is outweighed by their higher efficiency.[2]
- Plant cost of gas based advanced fuel-cell – \$600–800/kW.
- Plant cost of coal–gas based fuel-cell – \$1000–1500/kW.[3]

Environmental performance (emmissions in grams/kWh)

1. For advanced fuel-cell with coal–gas:
   - CO_2– 850–950;[4]
   - SO_2– 90% reduction; and
   - NO_x– 0.036–0.126.[3]

2. For advanced fuel-cell with gas:
   - CO_2– 450–500,[4] and
   - NO_x– 0.018–0.072.[3]

Efficiency

MCFC chosen for commercialization will have a fuel-to-electricity conversion efficiency of 54–60%.[1] The efficiency of a gas based advanced fuel-cell is 50–55% coal–gas based advanced fuel cell is 45–52%.[3]

Comments

There are some technical challenges in developing fuel-cells Current produced is proportional to the surface of the electrode. That implies need for large plates of about one square meter area with porous surface. Expensive catalysts are required in the low temperature fuel-cells to help accelerate the sluggish electrons. The electrolyte is relatively a poor conductor, and so the electrolyte layer has to be sufficiently thin [1]

The MCFCs operate at a high temperature of about 1200 °C PAFCs operate at much lower temperatures (around 200 °C). So PAFCs need an external fuel processor to reform methane and water to hydrogen and CO This reduces the efficiency and increases the cost and space occupied by the PAFC. In MCFC, the reforming takes place inside the cell itself because of the high operational temperature, thus, increasing its efficiency and reducing emissions.[1]

MCFCs will have the capability of using the most efficient way of consuming fossil fuel in the form of gas produced by coal gasification. Fuel-cells can respond to load changes within seconds making them perfect for serving peak loads and function effectively at either full or partial power [1]

References

1 Fuel cells for urban power, John Douglas, EPRI Journal, September 1991, 4–11

2 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

3 Energy from fossil fuels, William Fulkerson, Roddie R Judkins, Manoj K Sangvi, Sc Am, Sept 1990, 129–135

4 Derived from estimated carbon emitted in [3] assuming complete conversion of carbon into CO_2 This is an approximation and sets an upper limit on CO_2 emission in the process

Ultra super critical steam technology (USC)

Description

USC involve technologies for improving steam conditions and for achieving ultra-super critical temperature and pressure for steam in coal-fired power stations [1]

Status

USC technology will be made possible by using the new materials that have come about as a result of the recent progress in material technology.[1]

Efficiency

With this technology, the efficiency of plants is expected to rise to about 44% which is around the value achievable using integrated gasification combined cycle [1]

Reference

1 Coal utilization technologies on Japanese electric power companies, Masashi Hatano, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12-14, 1989. 339–359

Integrated coal gasification combined cycle (IGCC)

Description

In the IGCC process, coal is converted to a gas that is burnt to rotate a gas turbine. The hot combustion gases are used to produce additional electricity by rotating a steam turbine. The sulphur in coal is usually converted to elemental sulphur and subsequently sold. This technology allows utilities to use either natural gas or coal whichever is available [1]

Coal is partially burnt in a limited supply of oxygen and steam, preferably at high pressure, to produce a fuel gas at about 400 °C The gas is two-thirds CO and one-third hydrogen The gasifier operates in reducing conditions and so the sulphur in coal is converted to hydrogen sulphide which is more amenable to removal than SO_2 Desulphurization with established technology takes place after the fuel gas has been cooled and washed The chlorine in the coal is removed with waste liquors and the nitrogen in the coal is converted into element nitrogen during the gasification The clean gas is then used to produce electricity as described above [2]

Status

Various commercial and near-commercial designs are available A 120 MW plant is in operation in USA, run by a consortium of the US and Japanese utilities A Dutch utility has ordered a 250 MW plant which is expected to be operational by 1993.[2] In India, a 6.2 MW IGCC plant based on the moving bed dry ash Lurgi process has been set up at BHEL, Trichy.[3]

Cost

An analysis of the power cost shows that for a 200–250 MW size plant, IGCC costs 9 3 cents/kWh in current dollars averaged over a life of 30 years assuming a 6% inflation rate.[1] According to Texaco (designers of one gasification unit), the capital cost of IGCC will be the same as that of a conventional plant, and running costs will be 10% cheaper, mainly because of greater thermal efficiency. Larger IGCC plants (> 400 MW) are comparable in cost with conventional plants, but smaller plants (< 200 MW) are expected to be more expensive.[2]

Capital cost in India – Rs 23 884–29 338/kW. Cost of electricity for an annual operation of 6000 hours in India – 96.4–157 8 paise/kWh depending on the type of gasifier.[3]

Environmental performance (emmissions in grams/kWh)

CO_2 – 750–850

SO_2 – very low

Nitrogen-dioxide – very low[2]

CO_2 emission for a IGCC plant rated at 950 MW is about 740 tonnes/GWh (740 g/kWh) of electrical energy produced.[4]

Efficiency

Efficiency of IGCC plants is between 38 and 40%,[5] about 8% more than conventional coal plants with FGD.[6]

According to Jonathan Pearse, the efficiency is 38–43%, depending on gas turbine inlet temperature [2]

Comments

Integrated gasifiers can be used to produce electricity from biomass which can be grown sustainably and thereby reduce the build up of CO_2 in the atmosphere [7] IGCC plants also have the following advantages (i) less water and land requirement, (ii) phased construction; (iii) low gestation period, (iv) high plant availability, (v) higher efficiencies even at low powers as 50–100 MW capacity; (vi) modular construction, and (vii) utilization of high sulphur coals available in Assam and north-eastern states of India. However, the suitability of the existing commercial gasifiers to high ash Indian coal is yet to be proven.[3] Fertilizer plants in India use IGCC for captive generation of power.[8]

References

1 What will be the fate of clean-coal technologies ? Philip C Cruver, Environ Sci Technol 23 (9), 1989, 1059–1060

2 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

3 Evaluation of coal gasification process for high ash Indian coals for power generation through IGCC systems, Urja 28 (4) October 1990, 53–65

4 Environmental emissions from energy technology systems The total fuel cycle, Robert L San Martin, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 255–271

5 The role of coal use and technology in the greenhouse effect, Irene M Smith Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 283–294

6 Potential fossil energy-related technology options to reduce greenhouse gas emissions, R Kane and D W South, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases" Paris, France April 12–14, 1989, 35–58

7 Alternative roles for biomass in coping with greenhouse warming, D O Hall H E Mynick, R H Williams Sc & Global Security 2 (1991) 1–39

8 Discussion with Dr Ajay Mathur, TERI

Atmospheric fluidized bed combustion (AFBC)

Description

In the fluidized bed combustion process, coal is mixed with limestone or dolomite and suspended in a combustion furnace in a medium of coal ash or sand using a stream of upward flowing air at a ratio of one part fuel to 99 parts bed material. The limestone absorbs sulphur, producing a dry and benign gypsum-like waste that can be used as fertilizer and as a construction material. This chamber burns coal more efficiently, combustion temperatures are about half of those of a conventional boiler (750–950 °C) This limits the formation of temperature-dependent NO_x.[1 2]

The AFBC system can be designed such that the bed is a static bubbling bed or a circulating bed. Circulating systems increase the potential reaction time and improve sulphur absorption and bubbling systems have lower capital costs.[1]

Status

Commercial AFBC units of capacities below 250 MW are available at an industrial scale. Intensive development programmes are on in Germany, Sweden, USA, and UK to

commercialize this technology at the utility scale.[1] FBC units are commercially available for capacities up to 150 MW in India.[3] BHEL has indigeneously developed a 10 MW capacity AFBC unit in India.[4]

Cost

A power cost analysis shows that for a 200–250 MW plant, the cost is 10.6 cents/kWh in current dollars averaged over 30 years assuming a 6% annual rate of inflation [2] AFBC units are considered to be competitive with conventional coal-fired plants with FGD systems.[1]

Environmental performance (emmissions in grams/kWh)

CO_2 – 900–1000.[1]

SO_2 – emissions can be cut by as much as 90% by this process [5]

NO_x – Formation of nitrogen dioxide is restricted by the relatively low temperature of the furnace but that encourages formation of nitrous oxide which contributes to greenhouse warming and stratospheric ozone depletion. [1]

Efficiency

AFBC is about 2% more efficient at energy conversion relative to a conventional boiler with FGD.[6]

Comments

The advantage of fluidized bed combustors is the flexibility in the kind of fuel that can be burnt in it — coal, oil shale, tree bark, cow manure, etc. The combustor has the additional ability to deal with combustion pollutants in the boiler itself [2] AFBC plants generate huge quantities of solid waste An AFBC boiler burning coal with 12% ash and 1% sulphur with limestone for 90% sulphur removal will produce approximately twice as much solid waste as a conventional coal-fired plant. AFBC is likely to be upgraded by the pressurized FBC in the coming years.[1]

References

1 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

2 What will be the fate of clean-coal technologies ? Philip C Cruver, Environ Sci Technol 23 (9), 1989, 1059–1060

3 Theme Paper on Coal use scenario in India, International Conference on Environmentally Sound Coal Technologies, Jan 15–18, 1992, Madras

4 Discussions with Mr L R Suri, TERI

5 Cleaning up coal Elizabeth Corcoran, Scientific American May 1991 107–116

6 Potential fossil energy-related technology options to reduce greenhouse gas emissions R Kane and D W South Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases" Paris France April 12–14, 1989 35–58

Pressurized fluidized bed combustion (PFBC)

Description

PFBC is similar to AFBC except that it operates at approximately ten atmospheres pressure This makes it more efficient and permits it to use smaller boilers which may be shop fabricated [1] Compared to AFBC which operates at a pressure of one atmosphere. PFBC plants permit the use of deeper combustion beds and slower fluidizing velocities which imply longer residence time for the gas in the bed This improves combustion efficiency and absorption of sulphur The high pressure reduces NO_x emissions [2]

Status

PFBC is in the early stages of commercialization in USA. Spain. and Sweden [2]

Cost

Capital cost – about $1300/kW [2] A power cost analysis shows that for a 200–250 MW plant. the cost is 10 6 cents/kWh in current dollars averaged over 30 years assuming a 6% annual rate of inflation. For a turbo-charged PFBC. the cost is 9 1 cents/kWh [1]

Environmental performance

The coal consumption for generating one kWh of energy is 310–325 gCE [3]
SO_2 – 90% capture is standard, 98% is achievable using 2% sulphur coal.[2]
NO_x – Over 75% NO_x reduction with the basic design. A further reduction of about 0.5 g NO_x/kWh is possible with NO_x reduction techniques (without catalytic reduction) [2]

Efficiency

PFBC is 6% more efficient than a conventional boiler [4] Its efficiency is 38–40% comparable to that of IGCC.[3] Net efficiency ranges from 42% at 80 MW to 44% at 350 MW. Greater than 99% combustion efficiency is achieved with a wide range of coal.[2]

Comments

Solid waste production in PFBC is a little less than that of AFBC per tonne of coal consumed. On a kWh basis, it is even lower because of higher thermal efficiency of the system.[2] In general, the capital cost of PFBC is comparable to that of a pulverized coal plant but it has higher efficiency and lower operating cost [5]

References

1 What will be the fate of clean-coal technologies ? Philip C Cruver, Environ Sci Technol 23 (9), 1989, 1059–1060

2 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

3 The role of coal use and technology in the greenhouse effect, Irene M Smith. Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris France April 12–14, 1989, 283–294

4 Potential fossil energy-related technology options to reduce greenhouse gas emissions. R Kane and D W South, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 35–58

5 Theme Paper on coal use scenario in India, International Conference on Environmentally Sound Coal Technologies, Jan 15–18, 1992, Madras

PFBC and topping cycle

Description

In the topping cycle, the combustion gases from PFBC would be heated by addition of a topping gas from a separate gasification system to feed a high temperature gas turbine.

Status

This technology is being developed in UK and USA.[1]

Efficiency

This technology promises an improvement in efficiency up to 45% [1]

Reference

1 The role of coal use and technology in the greenhouse effect, Irene M Smith, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 283–294

Coal beneficiation

Description

Coal beneficiation refers to physical and chemical clean-up of coal before combustion. Vigorous physical and chemical clean-up of coal can reduce the sulphur content of some varieties of coal appreciably [1]

The physical treatment involves a number of processes like grinding, crushing, and various washing methods like froth flotation, hydroclones. and dewatering They exploit the difference between the specific gravity of the inorganic sulphur compounds and the coal. The process helps in reducing the ash and sulphur content of the coal, reduces volume and transportation costs, makes coal amenable to uniform heating and combustion.[2]

More advanced physical cleaning techniques can remove higher percentages of sulphur and ash by using characteristics like magnetic susceptibility and wettability of the different components of coal Chemical and biochemical techniques could remove organically bound coal sulphur and have the potential to substitute post combustion desulphurization [2]

Status

Physical cleaning of coal is widely practised in industrialized countries with coal reserves Majority of mined coal is washed in Germany. UK. and USA Advanced physical cleaning, chemical and biochemical methods are in the research and development phase [2] There are no washeries for power grade coal in India.[3]

Cost

- Conventional physical cleaning – \$5–7/t cleaned coal (USA and Europe),
- \$150–200/t sulphur removed
- Advanced physical cleaning – \$800–1200/t sulphur removed

Further offsets to these costs may be attained in terms of reduced transportation costs [2]

Capital cost for setting up washeries in India taking into account the net capacity of coal based power plants by the year 2000 is \$585.58 million (Rs 9 7 million at 1990 prices).[3]

Environmental performance

Physical cleaning of coal can reduce SO_2 emissions and generation of fly-ash during combustion.[2,3]

Comments

Indian coal is of poor quality and contains up to 50% ash Coal is often transported over large distances for power generation. It would make much more economic sense to transport better quality coal. Huge quantities of ash and fly-ash are generated when coal is burnt at the power stations There are problems associated with their disposal for which large tracts of lands are rendered useless For this purpose, it would be useful to have coal washeries at the pit-heads.[4]

The net average efficiency of the thermal power plants in India is 25% High ash coal by itself does not lower the efficiency. However, the coal obtained from open cast mines have a high component of non-coal material like shale and rock Thus, washing the coal before it is supplied would raise the boiler efficiency to 89 5% from 77% with unwashed coal The net efficiency will increase to 29.5%. CO_2 emissions will go down by 192 25 metric tonnes over the lifetime of the existing thermal power plants [3]

References

1 Cleaning up coal, Elizabeth Corcoran, Scientific American, May 1991, 107–116

2 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

3 Collaborative study on strategies to limit CO_2 emissions in Asia and Brazil TERI - India Paper sub UNCED November 1991

4 The answer is cleaner coal, T Ramchandran, Indian Express, Ahmedabad edition January 17, 1992

Coal-fired gas turbine

Description

This system uses a three-stage high pressure combustion process Coal is first burnt at a very high temperature (1820 °C) in a fuel rich zone with a limited amount of air The coal is only partially burnt and there is not enough time for oxygen or nitrogen to combine with air to form large quantities of NO_x The fuel rich gases are then doused with water in a quench zone, essentially freezing their low amounts of NO_x Quenching the gases lowers the temperature and solidifies coal ash so it can be removed before harming the turbine Combustion is then completed in a third, fuel-lean zone [1]

Status

A 4 MW gas turbine fuelled by a finely ground coal and water mixture has been tested by Allison Gas Turbines. The test, the first of its kind in which a modern turbine ran long enough without damage, showed that complete and stable combustion of the fuel occured and the turbine performed as designed.[1]

Cost

Total cost of the project is $38.3 million.[1]

Comments

Fuel for the tests was made from sub-bituminous low-sulphur coal Work is in progess to develop a dry pulverized coal feed system to replace the slurry fuel system and lower costs, and for developing advanced techniques for removing sulphur pollutants and small fly-ash particles [1]

Reference

1 Coal-fired gas turbine, Urja 31 (2), February 1992, p12

Micronized coal combustion

Description

This system consists of a coal storage system, feeding facilities, a micronizing rotary mill, burner, and automatic combustion control system In this process, coal is micronized to a minimal fineness of 80% less than 40 microns as compared to 75% less than 74 microns for conventional power plants, which has been arrived at by optimizing mill power, mill maintenance and combustion efficiency of a conventional boiler [1]

Status

This system has been succesfully adopted for the high reactive brown coal. It has been in operation in USA since the early eighties and in Europe since the late eighties operating on bituminous coals. The mill size ranges from 3 to 30 MW and has a power requirement of 18–20 kWh/t of coal [1]

Comments

The flame produced by the micronized coal combustion system is similar in all respects to oil and gas flames with high emissivity. Thus, it is a technically viable option to gas and oil fuel for retrofit in older plants. Other advantages of the system are: (i) rapid

response to overload; (ii) low noise level; (iii) simple fuel control by variable speed screw; (iv) simple control of secondary and tertiary ratio to control oxygen or NO_x level in the exhaust; (v) ability to change the shape of the flame to suit different types of heating load; (vi) multi-fuel operation is possible with proper burner design, (vii) flexible plant layout due to pneumatic conveying of the micronized coal from the mill to the burner; and (viii) suitability for small size boilers or direct firing applications such as in cement industry and heat treatment furnaces [1]

Reference

1 Energy scenario and emerging coal-based technological options, Ram K Iyengar, Urja 27 (2), February 1990, 25–28

Mechanical collectors

Description

Mechanical collectors are means to control the emission of particulates in the flue gas. The flue is spun in a cyclone, and the particulates are removed by centrifugal force Efficiency falls sharply for particles smaller than 5 microns [1] Cyclone is basically an inertial separator without moving parts and separates particles from the gas by transforming the velocity of the inlet stream, employing centrifugal force, into a double vortex within the cyclone The particles, owing to the inertia, move towards the outside wall and slide down the cyclone wall into the cone When the gas volume is more or a higher efficiency is required, multicyclone with small high efficiency cyclones are arranged in a casing Gas enters the cyclone cells axially and turns into a spiral motion via the vanes of the spinners.[2]

Status

Mechanical collectors are unable to meet emission standards, so they are not widely used However, they are used for primary collection in large boilers, FBC boilers, and as scalpers upstream of Selected Catalytic Reduction systems to prevent excessive catalytic abrasion [1] In India, most of the older plants are equipped with multi-cyclones and are being replaced with electrostatic precipitators in retrofit programmes to meet the present regulatory standards [2]

Cost

Levelized annual cost is 10–20% of the cost of installing and operating an electrostatic or filtration system.[1]

Capital cost of mechanical collectors for a plant capacity of less than 100 MW in India is Rs 5–10 lakhs [3]

Environmental efficiency

There is 90% efficient particulate removal.[1]

Mechanical collectors made in India have collection efficiencies around 60% for plant capacity of less than 100 MW [3]

References

1 Technology choice, Jonathan Pearse Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

2 Air pollution system in thermal power plants T K Ray, Urja 31 (3), March 1992 29–35

3 Discussion with Dr Ajay Mathur, TERI

Electrostatic precipitators (ESP)

Description

An ESP is basically an electric equipment where a DC voltage is imparted through discharge electrode creating an electric field around it. Dust particles carried by the flue gas, while passing through the field is charged to saturation and migrate towards the collecting electrode, usually in the form of plate curtain, where they are deposited in layers. By suitable rapping, the dust is dislodged into the hopper.

ESP is available both in horizontal and vertical gas flow as well as dry and wet collection In power plants, dry horizontal gas flow type precipitator is predominantly used.[1]

Status

ESP units have a long record of use in power plants [2]

Cost

- Capital cost – Approximately 4% of total plant cost.
- Operating cost – 5–8% of total plant cost.[2]
- Cost of ESP for a 210 MW plant – Rs 7–9 crore in India
- Cost of ESP for a 500 MW plant – Rs 15–20 crore in India [3]

Environmental performance

There is 99 5% efficient particulate control.[2]

Comments

Modern ESP is designed for gravimetric efficiencies of the order of 99%. Such efficiencies are achievable, provided the maintenance is good. Efficiencies are relatively insensitive to particle size but grade efficiency curves indicate a minimum in the 0.2–2 0 micron range.[4] Efficiency is greatly reduced by fly ash of high electric resistivity, usually associated with low sulphur coal. Efficiency is also sensitive to gas flow rates.[2]

References

1 Air pollution systems in thermal power plants, T K Ray, Urja 31 (3), March 1992, 29–35

2 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

3 Discussions with Ms Mala Damodaran, TERI

4 Access to modern energy technologies and their tranfer to developing countries, R K Pachauri, Mala Damodaran TERI, New Delhi, sub DIESA/DRPA, United Nations, 1991

Fabric filters

Description

Fabric or baghouse filters depend on both direct and electrostatic interception With woven fabrics, the dust layer itself builds up and improves collection efficiencies for removing finer particles, even better than clean filters The depth of material is important in the case of non-woven fabrics and is used in applications using high gas flow.[1,2]

Status

Fabric filters are widely used in coal-fired plants in USA [3]

Cost

- Capital cost – less than 4% total capital cost of the plant
- Operating cost – 5–8% total running cost of the plant [1]
- Annual cost (including water and power, maintenance, operating, capital, and insurance cost) is \$14–23/yr/m^3 of particulate removed depending on the texture of the fabric [4]

Environmental performance

There is 99 5% efficient particulate control.[1] Efficiency is lower for finer particles of size 0.1–1.0 micron [4]

Comments

For submicron particles, fabric filters have the most superior collection efficiencies [2] Efficiency is reduced by humidity but unaffected by fly ash resistivity and is not sensitive to gas flow rates Fabric filters are particularly useful for burning low sulphur coal Spraying wet lime into the flue gas ahead of the filter allows up to 85% of removal in plants burning low sulphur coal.[1] The quality of the fabric determines the performance of the bag filter. Introduction of non-woven fabrics like fibre glass, ryton, and teflon capable of withstanding temperatures up to 280 °C and resisting chemical attacks are suitable for use in bag filters for thermal power plants.[3]

References

1 Technology choice, Jonathan Pearse Environmental Considerations in Energy Development published by the Asian Development Bank 1991, 127–182

2 Access to modern energy technologies and their tranfer to developing countries, R K Pachauri Mala Damodaran TERI, New Delhi sub DIESA/DRPA United Nations, 1991

3 Air pollution systems in thermal power plants T K Ray, Urja 31 (3) March 1992 29–35

4 Fundamentals of Air Pollution - Second editiors Arthur C Stern, Richard W Boubel D Bruce Turner Donald L Fox, Academic Press Inc, 1984, p426

Wet scrubbers

Description

Wet scrubber is a venturi device which is used to collide particles with slower moving liquid droplets which constitute the scrubbing liquid The mechanism controlling the removal is inertial impact, except in a few cases where simple diffusion and condensation may be significant The scrubbing liquid is dewatered prior to disposal or treated via a settlement pond [1,2]

Status

Wet scrubbers are very common They are largely confined to low sulphur coal-fired plants in Western USA, and for high temperature and pressure applications as in IGCC and PFBC. Some are designed as hybrid SO_2 removal units.[1]

Cost

Annual cost (including water and power, maintenance, operating, capital, and insurance cost) is \$56/yr/m^3 of particulate removed [3]

Environmental performance

95–99 5% efficient particulate control. Lower efficiency in the 0.1–1 0 micron particle range. CO_2 emission increases by 3%.[1]

Efficiency

Flue gases require reheating before emission to the atmosphere Energy demand is 3% of the total plant output [1]

Comments

The performance of the scrubber is limited by the maximum value of the inertial parameter, which, in turn, is related to the pressure drop over at any stage Larger pressure drops require more energy and therefore, the system is costly to operate but that might be necessary for efficient collection of smaller particles [2]

References

1 Technology choice Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

2 Access to modern energy technologies and their tranfer to developing countries R K Pachauri, Mala Damodaran TERI, New Delhi, sub DIESA/DRPA, United Nations, 1991

3 Fundamentals ot Air Pollution - Second editors, Arthur C Stern, Richard W Boubel, D Bruce Turner, Donald L Fox, Academic Press Inc, 1984, p426

Wet DeSOx technology

Description

The wet FGD (flue gas desulphurization) is a non-regenerable system mainly involving the use of limestone and water [1 2] The SO_2 gas generated by combustion comes into contact with limestone–water slurry and gets absorbed in it The SO_2 gas is recovered as gypsum as a by-product This process uses a lot of industrial water and a relatively complicated waste-water plant is needed to treat the waste water [2] Systems may also use slurry or solution containing calcium, nitrogen or ammonia based absorbents or even sea water which is alkaline.[1]

Status

Wet scrubbing FGD systems using limestone slurry are in operation all around the world, chiefly in West Germany and Japan. Also in USA, Austria, Denmark, Czechoslovakia, and Turkey Those using other slurries are used in plants in USA, West Germany, and Japan [1]

In India, barring Trombay power station of the Tata Electric Companies, no other project is equipped with this facility with seawater and some limestone slurry scrubbing The sludge produced is sold off The equipment is not yet produced locally and could cost up to Rs 100 crore for a 500 MW unit at the prevailing exchange rates [3]

Cost

- Capital cost – \$81/kW (West Germany), \$155/kW (Japan), \$170/kW (USA),[1] \$175/kW (India) [4]
- Levelized annual cost – 0 33 cents/kWh (West Germany), 0 63 cents/kWh (Japan), 0 64 cents/kWh (USA),[1] 1.8 cents/kWh (India).[4]

  The most important factors influencing costs are fuel quality, capacity, and discount rate [1]

Environmental performance

CO_2 – increases by 1–1 5% due to increased energy consumption [1]

SO_2 – more than 90% can be removed by this process [2]

Efficiency

A non-regenerable FGD system uses 1–1 5% of the plant energy output [1] A typical steam plant outfitted with scrubbers runs at an efficiency of about 34% [5]

Comments

These systems can be retrofitted to existing power stations[1] and installed in both conventional coal-fired and oil-fired plants Gypsum, produced as a by-product in limestone slurrying process, can be used to make boards or as a cement additive [2]

References

1 Technology choice Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

2 Coal utilization technologies on Japanese electric power companies Masashi Hatano Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris France April 12–14 1989, 339–359

3 Govt urged to drop FGD stipulation, Naresh Minocha, Indian Express, Ahmedabad edition, December 28, 1991

4 CEA, based on EPRI study and pub in Modern Power Systems, July 1988

5 Energy from fossil fuels, William Fulkerson Roddie R Judkins and Manoj K Sangvi Sc Am, Sept 1990 129–135

Dry DeSOx technology using activated charcoal

Description

Dry DeSOx technology uses activated charcoal to adsorb sulphur components in the flue gas It uses much less industrial water compared to a wet scrubber and produces sulphur as a by-product in an effort to eliminate SO_2 emissions from coal and oil-fired plants [1]

Status

This technology is in the research and development stage in Japan [1]

Comments

Since the molecular weight of sulphur is less than that of gypsum, the amount of by-product is also minimized compared to a wet scrubber using limestone slurry [1]

Reference

1 Coal utilization technologies on Japanese electric power companies Masashi Hatano Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris France April 12–14 1989, 339–359

Spray dry scrubber

Description

The absorbent material, the principal type used being lime spray dryer, is injected as a solution or suspension and SO_2 from the flue gas is removed to produce a by-product that is usually collected along with the fly-ash [1,2]

Status

Spray drying systems are in use or being constructed in plants in Western Europe, Scandinavia, and in USA.[1]

Cost

- Capital cost – \$136/kW (US) [1]

Environmental performance

SO_2 – 65–96% efficient sulphur removal [1]

Comments

Spray dry scrubbers can be retrofitted to existing systems The dry by-product is suitable for landfill These systems have become a major alternative to wet scrubbers using limestone slurry.[1]

References

1 Technology choice Jonathan Pearse Environmental Considerations in Energy Development published by the Asian Development Bank, 1991 127–182

2 Coal utilization technologies on Japanese electric power companies, Masashi Hatano Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris France April 12–14 1989, 339–359

Wellman–Lord and magnesium oxide process

Description

These are regenerable FGD systems in which the scrubbing system is regenerated and recirculated, and the SO_2 is recovered from further processing to elemental sulphur or sulphuric acid [1] In this process, SO_2 is removed from the flue gases by reaction with a wet sorbent—sodium sulphite in the case of the Wellman–Lord process or magnesium oxide The reaction product is then separated and the sorbent is thermally regenerated. The recycling of the sorbent leaves a concentrated stream of SO_2 which can be processed into sulphur, sulphuric acid or liquid SO_2 [2]

Status

Regenerable FGD systems have been installed in generating plants in Germany, Czechoslovakia, and the US They are relatively rare compared to the non-regenerable FGD systems because of high capital costs [2]

Cost

- Capital cost (Wellman-Lord) – \$120/kW (Germany), \$255/kW (USA) [2]

Environmental performance.

SO_2 – 90–98% efficient sulphur removal. No solid waste.[2]

Comments

These systems may be retrofitted to existing plants. They have high capital and annual costs. Though they have high removal efficiencies, they are not common. Saleable markets for sulphur or sulphuric acid are also needed for these systems.[2]

References

1 Access to modern energy technologies and their tranfer to developing countries R K Pachauri Mala Damodaran TERI, New Delhi, sub DIESA/DRPA, United Nations, 1991

2 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

In-furnace sorbent injection

Description

Finely pulverized lime or limestone sorbent is injected directly into the furnace to react with the combustion gases. The efficiency of sorbent injection is less than other FGD (flue gas desulphurizing) systems and this process is often supplemented with further SO_2 removal processes before or after combustion.[1 2]

Status

Sorbent injection FGD systems are in existence or under construction in a total 3108 MW capacity of generating plant in Western Europe, Scandinavia, and North America [1]

Cost

It is a relatively low-cost strategy for removal of SO_2 [3]

Environmental performance

SO_2 emissions – 30–60% efficient sulphur removal
In hybrid systems – 60–95% efficient sulphur removal

Comments

May be retrofitted to existing power stations Most existing units are small, fitted to

plants of less than 100 MW capacity where coal sulphur contents are low (< 2%). Non-hybrid sorbent injection could be a suitable alternative in countries with low-sulphur-content coal and with less stringent emission standard.[1]

References

1 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank 1991, 127–182

2 Changing prospects for natural gas in the United States, W M Burnett and S D Ban Science 244 (1989), 307–310

3 The role of coal use and technology in the greenhouse effect, Irene M Smith Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases" Paris, France April 12–14, 1989, 283–294

Gas reburn with sorbent injection

Description

The alkaline sorbent is introduced in the duct between the boiler and the stack.[1] Gas reburn can be enhanced with the use of calcium-based sorbent in the gas reburning chamber.[2] The sorbents could be calcium carbonate (limestone) or calcium hydroxide hydrate (slaked lime) and these are injected along with reburn gas and air The sorbent is calcinated in the reburn zone and the SO_2 gas is captured during reaction with the sorbent [3]

Status

Systems are undergoing experimentation in USA [3]

Cost

Their estimated cost is 5–8% of a new generating system [3]

Environmental performance (per cent emission removal)[3]

SO_2 – 60% upwards

NO_x – 60% upwards

References

1 The role of coal use and technology in the greenhouse effect Irene M Smith Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases" Paris, France April 12–14, 1989, 283–294

2 Natural gas "Select-use" technologies Opportunities for emissions reduction using natural gas in conjunction with coal, Lee Solsbery, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 377–395

3 Changing prospects for natural gas in the United States, W M Burnett and S D Ban Science 244 (1989), 307–310

Low-NO_x combustion technologies

Description

Formation of NO_x in boilers is dependent on the availabilty of oxygen and the boiler temperature More the oxygen and higher the temperature, greater is the production of these oxides. Unlike SO_2, significant fractions of nitrogen in the fuel can be removed at the source by controlling the temperature and the availability of oxygen. This forms the basis of the low-NO_x combustion technologies [1,2]

The combustion temperature can be lowered by controlled combustion of the air or by mixing the flue gas to achieve slow and low-NO_x combustion [1,2] Fine pulverization of coal so that 95% of the particles have diameters less than 0 09 mm and none greater than 0.2 mm, reduces the air required in the boiler. Combustion could also be conducted in stages by introducing either the fuel or the air in stages. In fuel staging, unburnt fuel is burnt in a secondary combustion stage in low oxygen conditions NO_x formed in the first stage are reduced to elemental nitrogen in reaction with hydrocarbons formed in the second stage Fresh fuel may be introduced in the second stage representing 15–25% of the total fuel energy The combustion is completed in the third stage with further addition of air Low NO_x burners introduce air in stages and reduce the formation of NO_x by 40% by converting the nitrogen in the fuel into elemental nitrogen Lean burn or PM (pollution minimum) systems produce fuel rich combustion zones by separating the fuel aerodynamically before burning [1]

Status

Lean burn systems are widespread in Japan and low-NO_x burners are common in Japan, Germany, and USA. Fuel and air staging are not so common but are found in Japan, Germany, Scandinavia, Holland, and USA [1] Low-NO_x technologies are being introduced in the gas-based plants in India.[3]

Cost

The costs of combustion measures are significantly lower than costs of flue gas NO_x removal [1]

- Levelized annual cost – 0.02–0 06 cents/kWh (Scandinavia) based on modifications to new or easy-to-retrofit 300–350 MW coal-fired plants resulting in 30% reduction of NO_x emissions Plants operate for 6000 hours/year at full load. A 25-year economic lifetime and a 6% discount rate is assumed [1]

Environmental performance

Low-NO_x burners have up to 50–60% efficient NO_x removal

Lean burn systems in combination with low-NO_x burners or flue gas recirculation can achieve up to 50% NO_x removal Fuel staging results in a 30–40% reduction in NO_x emissions, 50–80% efficient removal can be achieved in combination with low-NO_x burners or flue gas recirculation 70% NO_x removal has been achieved in Sweden using natural gas as the reburning fuel Air staging is found to give 20–40% efficient NO_x removal [1]

References

1 Technology choice Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank 91, 127–182

2 Coal utilization technologies on Japanese electric power companies Masashi Hatano Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases" Paris France April 12–14, 1989 339–359

3 Discussion with Dr Ajay Mathur TERI

Selective catalytic reduction (SCR)

Description

This is a $DeNO_x$ technology applied to the post flame phase to reduce/eliminate NO_x emissions in the flue gas In this process, ammonia is injected into the flue gas which transforms NO_x into water and nitrogen gas in the presence of a catalyst [1] The process is selective at an operating temperature between 300 and 400 °C since the other components in the flue gas remain unaffected. The most commonly used catalyst is titanium oxide, others include activated carbon, iron oxides, and zeolite (aluminium silicate) Zeolite is crystalline and can store excess ammonia thereby preventing it from escaping into the environment [2]

Status

SCR systems have been fitted to coal-fired plants in West Germany and Japan They have also been fitted to oil and gas-fired steam turbines and gas turbine plants particularly in California, USA where NO_x emission standards are very stringent.[2]

Cost

- Capital cost – $91/kW (Germany), $53–71/kW (Japan), $102/kW (USA)
- Levelized annual cost – 0 34 cents/kWh (Germany), 0.35 cents/kWh (Japan), 0.66 cents/kWh (USA)

Most important factors influencing the costs are the cost of the catalyst and lifetime [2]

Environmental performance

The NO_x removing efficiency of this process is of the order of 80%[1] and 60–90% [2] This process does not produce any by-products for disposal CO_2 emission increases by 0 2–0 6%.[2]

Efficiency

Catalyst activity is sensitive to particulates in the flue stream Catalysts tend to last for 3–4 years in units placed close to the flue inlet, catalysts in 'tail-end' units can last upto six years, but the flue gas needs reheating for NO_x reduction to proceed [2]
SCR consumes 0 2–0 6% of plant energy output [2]

Comments

The major problem associated with SCR is that of ammonia slip The quantity of ammonia injected into the flue gas must be carefully matched with the quantity of NO_x present Modulation of the process relies on monitoring the flue gas flow rate and the NO_x concentration at the flue inlet. Feedback delays imply the occurence of periodic excess of ammonia which gets released into the atmosphere. Ammonia is a highly volatile and toxic gas It must be transported and stored in pressurized tanks and is subject to safety regulations in most countries.[2] It is too expensive a technology for adoption in India.[3]

References

1 Coal utilization technologies on Japanese electric power companies, Masashi Hatano Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases" Paris, France April 12–14, 1989, 339–359

2 Technology choice Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991 127–182

3 Discussion with Dr Ajay Mathur TERI

Selective non-catalytic reduction (SNCR)

Description

Ammonia is used in the absence of a catalyst to reduce NO_x to elemental nitrogen at temperatures between 900 and 1100 °C. The process is particularly sensitive to the operating temperature and produces excess ammonia or NO_x when the temperature is outside the optimal range Urea may be used instead of ammonia The reaction then produces ammonia and CO_2 Urea and enhancers allow the process to take place at lower temperatures [1]

Status

There are SNCR units fitted to coal-fired plants in Germany, Austria, Denmark, Sweden, and the Netherlands [1]

Cost

- Capital cost – $11–53/kW (West Germany, Austria).
- Levelized annual cost – 0 02–0 06 cents/kWh (Scandinavia) based on modifications to new or easy-to-retrofit 300–350 MW plants [1]

Environmental performance

There is 50–80% NO_x removal efficiency.[1]

Comments

As with the SCR system, the major problem in the SNCR system is that of ammonia slip which is enhanced by the high viscosity of the flue gas and the propensity of the process to generate ammonia.[1]

Reference

1 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991 127–182

Regenerable FGD/SCR system: activated carbon process

Description

Flue gases are first cooled in a heat exchanger, then passed through a counter current of activated carbon pellets at a temperature of 90–150 °C SO_2 is oxidized on the surface of the pellets by water and oxygen in the flue gas forming sulphuric acid which is adsorbed by the carbon Ammonia is injected at the same time to reduce NO_x to nitrogen and water The flue gas and nitrogen is then discharged from the stack and carbon pellets are regenerated. In the regenerator, SO_2 is produced again using the heat from the flue gas at temperatures between 400 and 450 °C. The carbon pellets are recycled and the SO_2 is used to produce sulphur, sulphuric acid or liquid SO_2 [1]

Status

The process is commercially proven Activated carbon units have been fitted to coal-fired plants in Germany and oil-fired plant in Japan [1]

Cost

- Capital cost – $300/kW (Germany)
- Operational cost – 1 1 cents/kWh (Germany), 0 8 cents/kWh desulphurization, 0 3 cents/kWh denitrification [1]

Environmental performance

SO_2 removal efficiency is above 95%. NO_x removal efficiency is 60–80% [1]

Comments

This system is likely to become increasingly important [1]

Reference

1 Technology choice Jonathan Pearse Environmental Considerations in Energy Development published by the Asian Development Bank, 1991 127–182

CO_2 scrubbing

Description

CO_2 scrubbing involves four basic steps — recovery concentration, liquefaction, disposal/reuse Concentration of CO_2 in flue gas is a key factor — typically 15–20% of

the flue gas is CO_2 by volume [1] It is obviously more advantageous to remove CO_2 from this large concentrated source than to remove it directly from the atmosphere where its concentration is only 0 2% of that in the flue gas [2] Though the capture and disposal of CO_2 from the flue gas of fossil fuel plant is technically feasible, it requires a significant fraction of the energy content of the fossil fuel and additional equipment with large capital expenditures [3]

Cost

EPRI estimates that the capital cost of CO_2 control on USA power plants will be of the order of $584 billion [1]

Efficiency

This will imply 20–50% derating in the plants.[1]

Comments

Finally CO_2 disposal and reuse is constrained by access and storage/market size [1] Commercial opportunities for the use of CO_2 as a raw material include its use for enhanced oil recovery in the beverage and chemical industries However, these requirements are miniscule in comparison with the amounts that would be produced.[2] CO_2 could be stored in depleted natural gas reservoirs,[4] disposed in the deep oceans[2 3], in salt caverns[2 5] or in aquifiers [5]

There is a great variation in the feasibility and economic assessment of CO_2 scrubbing technology options that are reported in literature A complex software ASPEN PLUS was developed in the MIT energy lab to generate the energy and material balances involved in different technology options. This calculates the energy required to capture CO_2 produced by coal consumption in different processes as a percentage of the heat content of the coal. The energy required for disposal/reuse of the captured CO_2 is not calculated [3]

References

1 Potential fossil energy-related technology options to reduce greenhouse gas emissions R Kane and D W South Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 35–58

2 CO_2 reduction and removal measures for the next century, Nebojsa Nakicenovic and Aviott John Energy 16 (11/12), 1991, 1347–1377

3 Feasibilty, Modeling and economics of sequestering power plant CO_2 emissions in the deep ocean H Herzog, D Golomb, S Zemba Environmental Progress 10 (1), 1991, 64–74

4 Technology and cost of recovering and storing carbon dioxide from an integrated gasifier combined cycle, C A Hendriks, K Blok, W C Turkenburg, Energy 16 (11/12), 1991, 1347–1377

5 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank, 1991, 127–182

CO_2 scrubbing by absorption

Description

This technique of chemical absorption is used by petroleum industry for acid gas removal. It involves scrubbing the flue gas with liquid solvents like amine and sea water [1] Specifically, it has been demonstrated that CO_2 from the flue gas can be scrubbed with solvents like monoethanolamine (MEA) or ecoamine (DGA) The solvent is subsequently stripped off CO_2 in a regeneration step and recycled back [2 3]

Status

There are two plants in USA that use MEA process, and one that uses DGA process The CO_2 produced is used as a raw material in either glass-making and chemical industry (as soda ash) or in the beverage industry [3]

Cost

- Capital cost – 119% total plant cost for coal-fired 79% for gas-fired (the Netherlands)
- Operational cost – 135% total plant cost for coal-fired 143% for gas-fired (the Netherlands).[4]
- Cost by lime absorption – 12 98 cents/kilo of carbon removed as CO_2 2 42 cents/kilo of carbon sequestered in deep oceans as CO_2
- Cost by MEA absorption – 12 1 cents/kilo of carbon removed as CO_2 2.42 cents/kilo of carbon sequestered in deep oceans as CO_2 [5]

Efficiency

It is possible to recover or concentrate 90% of the CO_2 by this process with a power derating of 30% More concentrated solvents could produce an efficiency gain by 30% and reduce the power derating to 20% [1] Typically, a plant with an efficiency of 40% might operate at a total net efficiency of 35% with CO_2 scrubbing [3]

The total energy requirement for the process is 47–79% of the combustion energy of coal as calculated by the ASPEN PLUS However, amine scrubbing accompanied by

cogeneration in a new plant designed for scrubbing can be more energy efficient [2]

Efficiency of removal of CO_2 in both lime and MEA absorption processes is 90% with a reduction of 59 and 57% respectively in plant efficiency [5]

Comments

The Dow Chemical Company has developed an amine technology called the FT technology specially targeted to remove CO_2 from flue gas Key operational problems involve corrosion, foaming, and solvent degradation Amine systems normally lead to corrosion problems since amines react with oxygen present in the flue gas to produce corrosive compounds Particulates in the flue gas result in foaming Solvent degradation is caused by the reaction of amine with SO_2 and NO_x in the flue gas to form stable salt which cannot be regenerated back to MEA All these contribute to the reduced efficiency. Thus for amine scrubbing, it is best to first free the flue gas of particulates and SO_2 [2]

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3 CO_2 reduction and removal measures for the next century, Nebojsa Nakicenovic and Aviott John Energy 16 (11/12) 1991 1347–1377

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5 Energy from fossil fuels, William Fulkerson Roddie R Judkins and Manoj K Sangvi Sc Am Sept 1990 129–135

CO_2 scrubbing by adsorption

Description

CO_2 in this process is adsorbed by clay Once the clay is saturated with CO_2, it is stored in pits [1]

Status

This technology is in the developmental stage.[1]

Efficiency

In case of a 90% CO_2 concentration, power derating approaches 50% of plant capacity [1]

Reference

1 Potential fossil energy-related technology options to reduce greenhouse gas emissions. R Kane and D W South. Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 35–58

CO_2 scrubbing by condensation

Status

This technology is in the initial development stages [1]

Efficiency

It will be possible to remove 90% CO_2 by this method with a power derating of 20–30% [1]

Reference

1 Potential fossil energy-related technology options to reduce greenhouse gas emissions. R Kane and D W South Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 35–58

CO_2 scrubbing by chemical/bio-chemical reactivity

Description

It relies on plankton/algae for photosynthesis These capture CO_2 and convert them into useable form like cellulose [1]

Status

This technology is not likely to be available until post-2000 under current development plans.[1]

Reference

1 Potential fossil energy-related technology options to reduce greenhouse gas emissions R Kane and D W South, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 35–58

CO_2 scrubbing by air separation/flue gas recycling

Description

This scheme involves prior enrichment of CO_2 in the flue gas by burning coal in an atmosphere of oxygen and recycled flue gas instead of air The three basic steps in the process are air compression and separation, combustion and power generation, and flue gas compression and dehydration The key energy requirements are compression of the inlet air prior to separation and compression of the flue gas for pipeline transport For retrofit applications, the main problems are maintaining the flame and heat transfer characteristics of the boiler and preventing air ingress [1]

Status

Research is underway at the Argonne National Laboratory, USA to develop this technology option [1]

Efficiency

According to the estimates of ASPEN PLUS as of now, this is the process that requires least incremental energy of the fossil fuel (30%) to scrub CO_2 The efficiency of the plant is reduced from 35% to 25% [1]

Reference

1 Feasibilty Modeling and economics of sequestering power plant CO_2 emissions in the deep ocean H Herzog D Golomb S Zemba Environmental Progress 10 (1), 1991 64–74

Cryogenic CO_2 fractionation of flue gas

Description

The process of EOR (enhanced oil recovery) involves cryogenic fractionation of a mixture of methane and CO_2. Comparatively, little work has been done on cryogenic fractionation of nitrogen and CO_2 The two systems are known to have similar character and distillation limitations, but the latter requires different operating conditions for temperature and pressure According to the published literature, several methods exist for fractionation of these gas-systems These are straight distillation, double column systems, use of an additive, and controlled freezing [2]

In straight distillation, there exists the possibility of formation of solid CO_2 in the distillation column Additives like butane and aromatics alter the phase diagram and prevent the freezing of CO_2.[1]

Efficiency

ASPEN PLUS has analysed the energy and material balance of the Ryan-Holmes process which uses this technique. Over 90% of the CO_2 in flue gas can be removed in this process at about 97% purity Flue gas has to be cleaned of fly-ash and SO_2 and dehydrated prior to fractionation. This process is estimated to consume 55–95% of the energy of coal [1]

References

1 Feasibility Modeling and economics of sequestering power plant CO_2 emissions in the deep ocean. H Herzog D Golomb, S Zemba Environmental Progress 10 (1), 1991, 64–74

2 Access to modern energy technologies and their transfer to developing countries, R K Pachauri, Mala Damodaran TERI, New Delhi, Sub DIESA/DRPA, United Nations, 1991

Separation of flue gas with selective membrane diffusion

Description

Gases in contact with semi-permeable polymeric membrane can be separated using the selective rates of diffusion of the different gas species across it [1]

Cost

Cost of molecular sieves—18 48 cents/kilo of carbon removed as CO_2 2.42 cents/kilo of carbon sequestered in deep ocean as CO_2 [2]

Efficiency

CO_2 can only be partially separated using a single membrane So, for the purposes of analysis by ASPEN PLUS, a double-stage process is used The overall CO_2 recovery in this process is about 80%. Energy consumption estimate is about 50–70% of the coal [1]

In CO_2 removal, an efficiency of 90% is possible using molecular sieves with an 80% reduction in the plant efficiency [2]

Comments

In the selective membrane separation process, there is an inherent limitation in the form of trade-off between permeability of the polymer membrane used and the purity of CO_2 separated.[3]

References

1 Feasibility, Modeling and economics of sequestering power plant CO_2 emissions in the deep ocean H Herzog D Golomb S Zemba Environmental Progress 10 (1), 1991, 64–74

2 Energy from fossil fuels, William Fulkerson Roddie R Judkins, Manoj K Sangvi Sc Am, Sept 1990 129–135

3 CO_2 reduction and removal measures for the next century, Nebojsa Nakicenovic and Aviott John Energy 16 (11/12), 1991 1347–1377

Scrubbing of the flue gas with sea water

Description

In this process flue gas at atmospheric or elevated pressure is brought in contact with sea water which acts as an absorbent for the CO_2 in the flue gas [1]

Comments

Sea water scrubbing for flue gas at atmospheric pressure either consumes vast quantities of energy or implies very high capital cost on huge pipelines for the seawater At elevated pressures, though the solubility of CO_2 in seawater is improved, maintaining high pressure to compress the gas is very expensive [1] Besides, there are many uncertainties associated with ocean disposal since there is little known about the diffusion rates, changes in deep ocean acidity, and related ecological questions [2]

References

1 Feasibilty, Modeling and economics of sequestering power plant CO_2 emissions in the deep ocean H Herzog, D Golomb, S Zemba Environmental Progress 10 (1) 1991, 64–74

2 CO_2 reduction and removal measures for the next century Nebojsa Nakicenovic and Aviott John Energy 16 (11/12) 1991, 1347–1377

Coal gasification shift process and CO_2 scrubbing with physical absorption

Description

A coal gasifier, as in an IGCC plant, is used to convert coal into a synthetic gas mainly consisting of hydrogen and CO. The IGCC plant consists of both steam and a gas turbine To recover carbon from the synthetic gas, a shift reactor and a CO_2 recovery unit is added to the basic IGCC design These are placed after the acid gas recovery

system which removes 99% of the original sulphur content of the synthetic gas This is necessary as the catalyst in the shift reactor is sensitive to sulphur During the shift reaction, CO and steam are converted to CO_2 and hydrogen. The shift reaction reduces the heating value of about 90% of the synthetic gas by 9%. This energy is lost for all practical purposes in the process The shifted synthetic gas has about 40% CO_2 at a pressure of about 10 bar This makes it amenable to be absorbed by a physical absorption process rather than use a chemical process which is more energy intensive but essential at lower partial pressures The absorbent used can be selexol, a 95% solution of dimethyl ether of polyethylene glycol in water. The synthetic gas flows counter current through selexol, which, after collecting the CO_2, is collected at the bottom of the unit About 65–75% of the CO_2 is subsequently recovered in a series of recycle flash drums by reducing the pressure. After the desorption stages, the selexol still contains 25–35% of the originally dissolved CO_2 This is recycled back to the absorber and recovered in later cycles [1] CO_2 can be subsequently disposed in depleted natural gas fields [1] or in the deep ocean [2]

Status

The process is in the experimental stage in the Netherlands and in USA and not available commercially [1 2]

Cost

Cost calculations based on the study by Hendriks et al , for the Netherlands [1] using an IGCC (of base capacity of 711 MW) with CO_2 recovery are

- plant investment costs – 2891 Dfl/kW net,
- specific plant O & M costs – 107 Dfl/kW net yr,
- electricity price – 8 7 Dct/kWh,
- costs of carbon recovery – 1 7 Dct/kWh,
- cost effectiveness – 25 Dfl/mt CO_2 avoided

[All costs are expressed in 1989-Dutch guilders (Dfl 1=$ 0 5)]

However, cost estimates by EPRI/IEA [2] for a similar system shows very different figures The cost of electricity goes up by 70% in that study for an IGCC with CO_2 recovery These differences are caused by lower discount rates and cost of coal in the Netherlands, smaller gasification plant, shorter pipeline, and pressure for CO_2 disposal in the study by Hendriks et al ,[1] as pointed out by Booras et al [2]

Cost of IGCC/selexol process—3 96 cents/kilo of carbon removed as CO_2 1 54 cents/kilo of carbon sequestered in natural gas wells as CO_2 [3]

Environmental performance

2502 kilo tonne of carbon emission is prevented every year [1]

Efficiency

Overall efficiency with carbon recovery is 38 1% as against 43 6% in case of stand alone IGCC [1] of 711 MW capacity

The efficiency of removal of CO_2 in IGCC/selexol process is 88% with a reduction of 13% in the efficiency of the power plant [3]

Comments

Scrubbing CO_2 from IGCC plants using this process is relatively cheaper than scrubbing CO_2 from conventional coal-fired plants though major CO_2 disposal expenses, e g , compressor and pipelines, are essentially the same for both plants Still, CO_2 scrubbing is a very expensive way of attempting to reduce the greenhouse effect [2] CO_2 disposal is the main problem since its reuse is limited [4]

References

1 Technology and cost of recovering and storing carbon dioxide from an integrated gasifier combined cycle C A Hendriks K Blok W C Turkenburg, Energy 16 (11/12), 1991, 1347–1377

2 An engineering and economic evaluation of CO_2 removal from fossil-fuel-fired power plants, G S Booras and S C Smelser, Energy 16 (11/12) 1991, 1347–1377

3 Energy from fossil fuels William Fulkerson, Roddie R Judkins, Manoj K Sangvi Sc Am Sept 1990 129-135

4 Technology choice, Jonathan Pearse, Environmental Considerations in Energy Development published by the Asian Development Bank 1991, 127–182

PART II

End-use

Continuous fibre ceramic composites

Description

This is a recent advance in fibre technology, which can strip ceramics of their characteristic brittleness. It consists of a composite material of continuous fibre embedded in a ceramic matrix. Like the cables and bars used to strengthen concrete, continuous fibres reinforce the ceramic to create a composite that is several times tougher and much less sensitive to strength limiting flaws than an unreinforced ceramic matrix.[1]

Status

The technology for continuous fibre ceramics is being implemented in the US industry [1]

Conservation potential

Nationwide implementation of this technology in the US could result in a saving of 0.17 667 quadrillion kcal by 2010 AD [1]

Application

Continuous fibre ceramic composites are good for a variety of industrial applications, e g., construction of advanced burners and combustors whose resistance to corrosion at high temperature is crucial [1]

Comments

Extensive use of this technology will improve air quality by reducing NO_x emissions Several industrial applications have been identified but their nationwide implementation will require active cooperation among industry, universities, and national labs in the US [1]

Reference

1 Boosting US energy efficiency through federal action. Eric Hirst, Environment 33(2) March 1991 p7

Float glass process

Description

This process involves casting sheets of plate glass on a smooth layer of molten tin.[1]

Status

This technology was adopted in the mid-60s in the US.[1]

Application

In glass manufacture.[1]

Comments

This process eliminates the energy needed to grind and polish glass after solidification [1]

Reference

1 Energy for industry, Marc H Ross and Daniel Steinmeyer, Sc Am, September 1990

Energy-efficient production of ammonia

Description

In an ammonia plant, streams of hydrogen and nitrogen gas pass over a catalyst at high pressure, causing a portion of them to combine The unreacted gases are recycled. A new geometric layout of catalyst surfaces has been developed which increases the contact between the reactants and the catalyst, thereby converting a higher fraction of the reactants into ammonia at every pass and increasing the production rate [1]

Status

The catalyst surfaces have been designed in the US by MW Kellog Company in Houston, Texas [1]

Conservation potential

The layout reduces the pressure needed to force the reactants through the catalyst bed and reduces the energy consumption by 5%.[1]

Reference

1 Energy for industry, Marc H Ross and Daniel Steinmeyer, Sc Am, September 1990

Rubber-coated air bags

Description

This is a device for reducing air leakage in compressed air systems serving large sheet-metal stamping press as in automobile parts The lower die of the press often involves a movable insert supported by an air cushion. As the press descends, the sheet metal is clamped by the frames of the upper and lower dies, then drawn as the insert is pushed down under the descending upper die The quality of the die is dependent on the smooth response from the cushion In conventional systems, pistons in cylinders pressurized with air from the plant system acted as die cushions These systems are being replaced by heavy-walled rubber air-bags to prevent leaks and conserve energy.[1 2]

Status

These bags have been developed by Smedberg Machine in the US and have been both retrofitted and installed in presses [2]

Conservation potential

Retrofitting presses would reduce plant wide compressed air requirement by 50% and overall electricity consumption by 25%.[2]

Application

In metal stamping presses.[1 2]

Comments

The conventional system with pistons tend to leak up to 0 05 m^2/second after about three months of use In a large stamping press this leakage amounts to about 4 MW of electric load. Repair implies taking the press out of service for a long spell thus stopping production Alternately, they have to be fed with air supply constantly which is a wasteful process. Rubber coated air bags not only reduce energy consumption, they also improve the consistency of the product and avoid maintenance expenditure.[1 2]

References

1 Improving the efficiency of electricity use in manufacturing, Marc Ross, Science 244 April 1989, 311–317

2 Energy for industry, Marc H Ross and Daniel Steinmeyer, Sc Am, September 1990

Automated process control

Description

Precise and efficient process control systems will be possible with sensors that can operate in the environmental extremes of many industrial processes. Innovative sensors, data processing capabilities, and artificial intelligence techniques will replace subjective judgements; improved process monitoring and enhanced real-time control will increase energy production and decrease the amount of waste and pollution associated with production processes.[1]

Status

Automated controls are being introduced in various industries at different levels all over the world.

Conservation potential

Feed-forward controls in distillation plants can reduce energy consumption by 5–15% Increased controls and use of sensors can reduce variation in pulp quality by 31% and reduce steam use by 19%.[2]

Applications

Automatic process control is useful in high temperature processes like measuring melting temperature and heat flux in glass-making and measuring alumina saturation in aluminium production. This process is also useful in low temperature applications as in measuring chemical compositions and agricultural growth conditions [1]

It is also applicable to distillation columns in which sensors are used in both the columns and the feedlines to collect data for feedforward operations—adjusting steam and product flows according to heat and mass transfer equations so that the column's final product will have the desired composition. Feedforward operations allow columns to be operated at higher feed rates Thus, a fully automated plant with the same production capacity costs less to build [2]

In paper industries, automated controls can optimize the combination of heat and chemicals required to produce high quality pulp, schedule timing of operations to reduce peak power requirements cutting energy costs further [2]

References

1 Energy efficiency and global warming, Alan J Streb, Presented at the IEA OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris France April 12 14 1989 87–113

2 Energy for industry, Marc H Ross and Daniel Steinmeyer Sc Am September 1990

Low pressure polyethylene process

Description

This is a process based on solvents which enables the development of a low pressure gas based technique to produce polyethylene.[1]

Status

The technology was introduced in the US in the mid-seventies by Union Carbide.[1]

Cost

Low pressure polyethylene process involves half the capital cost of the improved high pressure process to produce polyethylene.[1]

Conservation potential

This process consumes only a quarter of the energy consumed by the high pressure polyethylene process.[1]

Comments

Polyethylene accounts for one-third of 18 18 billion kilograms of plastic produced in the US in 1989. In 1940s when it was first manufactured, it was produced under high pressure of 12 000 atmospheres The new low pressure process has its origin in some fundamental discoveries made by European chemists in the 1950s [1]

Reference

1 Energy for industry, Marc H Ross and Daniel Steinmeyer, Sc Am , September 1990

Electric heating

Description

Electric heating processes can achieve almost unlimited energy densities in materials [1] These processes include the following.[2]

- Arc heating.
- Electrolytic furnaces.
- Resistance furnaces.
- Induction heating
- Dieletric heating.

- Electromagnetic heating (microwave).
- Electron beam.
- Laser.
- Far infra-red.

Status

Most of these technologies are mature commercial technologies.[3]

Cost

The cost may be evaluated from the electricity needs of these technologies in one million kWh for evaluating the substitution potential of combustion processes by electric heating [2]

- Arc heating – 19 893.
- Electrolytic furnaces – 3400.
- Resistance furnaces – 6000.
- Induction heating
- Dieletric heating – 112 5
- Electromagnetic heating (microwave) – 1.2.
- Electron beam – 1.2
- Laser – 3.5.
- Far infra-red – 3600.

Conservation potential

CO_2 emissions in terms of 1000 tonnes of carbon for these technologies are given below.[2]

- Arc heating – 2490
- Electrolytic furnaces – 430
- Resistance furnaces – 750
- Dieletric heating – 14
- Electromagnetic heating (microwave) – 1 6
- Elecron beam – 0 1
- Laser – 0 4
- Far infra-red – 375

Efficiency

Heat efficiencies of these technologies are as follows [2]

- Resistance furnaces – 20–30%

- Induction heating – furnace 60–80%, heating 70–80%
- Dieletric heating – 45–65%
- Electromagnetic heating (microwave) – 45–65%
- Far infra-red – 60–80%

Application

Plasma arc temperatures upto 10 000 °C are routine compared to a maximum of about 3000 °C achievable with the best combustion process Heat transfer and chemical reactions occur at extremely high rates at plasma temperatures Electromagnetic energy in the form of lasers and electron beams can be focused to produce power densities on surfaces more than million times that of a combustion heated process Dielectric dissipation as with microwaves can produce high rates of volumetric heating within materials.[1]

Comments

Electric heating technologies are characterized by speed, close control, high efficiency, no pollution, and smaller labour requirements These advantages are important to companies in global market where production efficiencies are more important than conserving electricity [3]

References

1 Improving the efficiency of elctricity use in manufacturing Marc Ross, Science 244 April 1989 311-317

2 Possibilities of carbon-dioxide reduction in the industrial sector, Naoto Sagawa Energy in Japan 111 September 1991, 14–24

3 Potential energy savings from efficient electric technologies, Clark W Gellings Ahmad Faruqui Ken Seiden, Energy Policy 19(3), April 1991, 217–230

Freeze concentration technology

Description

This is an electricity-based separation technology. It is based on the preference in phase-change for one component in mixed liquids, as in the common vaporization separation process. Heat is removed from the mixture until crystallization sets in, then the crystals are physically separated and melted. The separated mixture is usually very pure.[1]

Status

This technology is being used in the US industries [1 2]

Conservation potential

As an example, it is estimated that only 12.5% of the energy needed by the conventional evaporators will be required in the electrically driven freeze process to make dried milk in the dairy industry.[1]

Application

In industries which involve separation processes (e g , petrochemical and dairy) [1 3]

Comments

Offers potential for improving energy efficiency and quality of product.[2]

References

1 Improving the efficiency of elctricity use in manufacturing. Marc Ross Science 244 April 1989 311–317

2 Potential energy savings from efficient electric technologies. Clark W Gellings. Ahmad Faruqui Ken Seiden Energy Policy 19(3). April 1991, 217–230

3 Energy efficiency and global warming, Alan J Streb, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris France April 12-14 1989. 87–113

Waste heat recovery

Description

Much of the waste heat generated in industrial processes over a wide range of temperatures can be recovered and reused [1]

Higher temperature waste heats mostly arise from combustion exhaust gases and refrigeration wastes and these are usually recuperated in waste heat boilers Low and medium grade waste heat may be recovered using heat pumps [2] Development of organic working fluids will improve the performance of organic Rankine cycle driven by low temperature waste heat [3] In addition to these, there are heat pipes and heat exchangers working with small temperature differences that may be used to recover waste heat [2] Ceramic recuperators and regenerators have been developed to recover heat from hot waste gases from industrial furnaces Ceramic heat exchangers will preheat combustion air to a temperature in excess of 1000 °C [4]

Optimizing and rationalizing process flow by energy cascading and cogeneration are other ways of utilizing process heat. Energy cascading is the placement of several processes requiring successively lesser quantities of energy in a sequence so that each uses the waste heat from the preceeding one.[3] Cogeneration is the simultaneous production of electric power and heat.[1]

Some specific waste heat recovery systems are given below.

1. Thermosiphon waste heat recovery boilers for exhaust gases This is a new explosion-proof construction with extended working life with a dual-circuit structure of the heat conducting system. It uses water as a working fluid [5]

2. Perforated-plate Multistage fluidized bed heat exchanger This is designed for heat recovery of gases containing particles or from high temperature granular particles. Its main advantages are compactness, gas–solid counter current, direct contact heat exchange, low pressure drops, and no clogging risks as compared to the overflow type heat exchanger. [5]

3. Hazen-metallic high-temperature Recuperator. This provides combustion pre-heat for furnaces in the steel and other metal industries Where heat is continuously transferred from the waste gases at high temperature to lower temperature air through a metal wall.[5]

4. Swirl burner/furnace for low calorific value gases A compact lightweight unit capable of sustaining the combustion of waste gases of as low a calorific value as 1.4 MJ/m^3 The clean high temperature can be used for process heating [5]

5. Circulating fluidized bed for heat recovery This is designed to burn gaseous fuels. It recovers heat with the help of vertical tubes in the form of steam or hot water Recovery is improved by the circulation of the bed material [5]

6. Gas–gas ceramic heat exchanger. This is used for heat recovery at elevated temperatures (1200 °C). It is made of silicon carbide and uses conjective jet impingement and radiation as the main heat transfer modes.[5]

7. Fluidized bed high temperature gas–gas heat exchanger. The system is used to provide a means of exchanging heat from a hot gas stream to a cold gas stream

utilizing a circulating fluidized bed of inert granular particles (alumina grit) as the heat transfer medium.[5]

8. Fluidized bed heat exchanger filter for waste heat recovery from dirty corrosive gases. This is used for efficient waste heat recovery from diesel exhausts or generally from factory hot flue gases. The system overcomes the problems due to high fouling property of exit gases.[5]

Status

Waste heat recovery techniques are used in many energy intensive industries, e.g., steel, petrochemicals. [1–4,6]

Thermosiphon waste heat recovery boiler is an established technology. It has been introduced and successfully operated with significant economic effect. Perforated-plate Multistage fluidized bed heat exchanger is in the R & D stage and its pilot plant unit is being promoted in France. Hazen-metallic high-temperature Recuperator has been commercially available since the 70s. The swirl-burner is an established technology. Circulating fluidized bed for heat recovery from both ordinary and dirty corrosive gases and gas–gas ceramic heat exchanger are in the R & D stage. Fluidized bed high temperature gas–gas heat exchanger is an established technology.[5]

Conservation potential

Estimates of the electric energy use for process heat that can be saved through waste heat recovery techniques ranges from 5 to 25%.[7] Ceramic heat recuperators will recover 2 exajoules of thermal energy per year in the US. Advanced heat exchangers will similarly recover 1.6–3.2 exajoules of process heat over 538 °C and new heat pump technology will upgrade 1.0–3.0 exajoule of process heat from liquid and gas waste streams at 66–121 °C, and bottoming cycle engines for streams at 371 °C and lower, to a more useful level Potential saving from process flow optimization is estimated to be 2.0 exajoules per year.[3] Ceramic heat exchangers can reduce fuel consumption by as much as 50% [4]

Application

In the power sector and in industries.

References

1 Energy efficiency and global warming, Alan J Streb, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 87–113

2 Present status and future prospects of energy utilization technology in Japan for greenhouse gas mitigation, Takao Kashiwagi, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 21–33

3 Effects of energy technology on global carbon dioxide emissions, prepared by M C Cheng, M Steinberg, M Beller, Process Science Division, Dept of Appl Sc, Brookhaven National Lab, Upton NY 11973 under CN-DE-ACO2-76CH00016 for US DOE Off of Energy Research, Off of Basic Energy Sciences, Carbon dioxide Research Division, Washington DC 20545

4 Energy technologies for the use of natural gas to reduce carbon dioxide emissions including Gas reburn technology for coal firing, Roland Pfeiffer, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 361–375

5 TIFAC-line Database

6 Industrial Energy Conservation - Case-Study Series 5, TISCO, TERI, September 1988

7 Potential energy savings from efficient electric technologies, Clark W Gellings, Ahmad Faruqui, Ken Seiden, Energy Policy 19(3), April 1991, 217–230

Efficient automobile

Description

The system converts about 30–40% of the fuel energy to useful work. Steps that involve loss of energy in driving motor vehicles are:

- energy lost due to friction in the engine and waste heat,
- engine power lost in the process of transmission and drive train;
- energy lost due to rolling resistance of tyres, and
- energy lost due to aerodynamic drag.[1]

Efficiency improvement can be effected by .

- reducing the vehicle size—small automobiles use less fuel because of less weight, fewer power options, and less aerodynamic drag;
- changing the vehicle design and material—reducing of vehicle power/weight ratio, varying compression ratio, improving the carburetor, reducing internal friction, higher gear ratios, continuously variable tranmission using belt-drive or other smoothly varying devices, automatic lock-up gear boxes, advanced radial tyres, better lubrication, use of light weight composite material;[2] and
- improving the vehicle engine—new, lightweight ceramic and ceramic composite engine components, alternate fuel technologies for modified conventional engines etc.[3]

- improving the vehicle engine—new, lightweight ceramic and ceramic composite engine components, alternate fuel technologies for modified conventional engines etc.[3]

Status

Continuous transmission exist for small cars; they are being developed for bigger cars.[1] Ceramic components are being developed for use in car parts and engine. Newer engines and alternate fuel technologies are also being developed in the US and Europe [1,3]

Conservation potential

Ceramic and composite materials will enable engines to operate at higher temperatures and thermal efficiency for longer times and have reduced emissions and maintenance.[3] Combination of continuously variable transmission with regenerative braking and energy storage systems can yield up to 30% fuel savings. Advanced radial tyres save up to 5% fuel Better lubrication reduces the frictional loss due to internal engine, transmission, and axle friction and saves up to 10% fuel. A 10% reduction in the vehicle weight could lead to about 7% improvement in fuel efficiency. A smaller car can average 40 mpg compared to 20–30 mpg for larger cars. Energy savings of about 35% can result from improved automobile propulsion systems.[2]

Overall improvements are expected to lower the fuel consumption by 65% to 40 mpg by 2050 AD,[2] saving 59 exajoules of fossil fuel energy.[3]

Environmental performance

Overall improvements are expected to save 33 792 kg of CO_2 [2]

Comments

According to Keepin and Kats, raising the average fuel consumption from 18 to 28 mpg would eliminate all OPEC oil imports in the US.[4]

References

1 Energy for motor vehicles, Deborah L Bleviss and Peter Walzer, Sc Am, September 1990, p103

2 Effects of energy technology on global carbon dioxide emissions, prepared by M C Cheng, M Steinberg, M Beller, Process Science Division, Dept of Appl Sc, Brookhaven National Lab, Upton NY 11973 under CN-DE-ACO2-76CH00016 for US DOE Off of Energy Research, Off of Basic Energy Sciences, Carbon dioxide Research Division, Washington DC 20545

3 Energy efficiency and global warming, Alan J Streb, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 87–113

4 Greenhouse warming - comparative analysis of nuclear and efficiency abatement strategies, Bill Keepin and Gregory Kats, Energy Policy, December 1986, 538–561

Electric cars

Description

Electric vehicles use rechargeable batteries and battery-driven propulsion systems [1]

Status

An ecologically desirable power unit for cars based on a battery-driven car was proposed by Lucas Electricals in the UK.[2] Advanced rechargeable batteries under study that may meet performance requirements of electrically propelled vehicles include sodium–sulphur, zinc–bromine, lithium–aluminium–iron sulphide, and iron–air.[1]

Conservation potential

Conserve petroleum product.[1]

Environmental performance

Eliminate vehicular emissions.[1]

Comments

There are problems associated with the storage and recharging of the batteries in electric cars. This could increase the weight of the car and make the car unsuitable for random and long journeys.[2]

References

1 Energy efficiency and global warming, Alan J Streb, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 87–113

2 Architect or bee ? The human price of technology, Mike Cooley, Revised Hogarth Press, London, 1987

Hybrid cars

Description

Hybrid vehicles combine the features of electrical and internal combustion engines. These could be designed in two different ways which are given below.

(1) One way is to make use of the high starting torque of an electric motor and the ability of a relatively small engine to power the vehicle as it moves along. A small combustion engine, running constantly at its optimum revolution and at its optimum temperature, drives a generator which, in turn, charges a very small stack of batteries. These act as a temporary energy store and supply power to an electric motor which drives the transmission system, or in a reversed version, will hub motors directly on the wheels. In general use, the internal combustion engine would be running continuously at its optimum rate. All the energy that is wasted as one starts from the cold, accelerates, changes gears or idles at traffic lights, would go into the system as useful energy [1]

(2) Another kind of hybrid car has a diesel engine, a small electric motor, a sodium–sulphur battery that operates at 300 °C, and a clutch that yolks the motor to the engine. When the accelerator pedal is pressed less than a third of the way down as it would be during most urban travel, the electric motor powers the car Further pressure on the pedal engages the clutch, so that the electric motor serving now as the fly-wheel, starts the engine as in case (1). The electric motor can also serve as the generator to recharge the batteries.[2]

Status

A prototype unit of hybrid car of the general type was built and tested under the direction of Prof Thring at Queen Mary College, London Similar hybrids are being developed in Japan and Germany [1] A hybrid car suitable for inter-city travel has been developed by Volkswagen in the US [2]

Conservation potential

The general type hybrid car is expected to improve the fuel consumption by 50% [1]

Environmental performance

The emissions of toxic fumes will be reduced by 80% as the engine running constantly at its optimum speed and temperature will ensure a more complete combustion of fuel [1] The Volkswagen hybrid does a hundred miles/gallon of diesel and 25 kWh of electricity If the electric charge source is non-fossil, 60% of CO_2 emitted by a vehicle of the same size would be eliminated.[2]

Application

Hybrid vehicles of the second type are particularly efficient for inter-city driving.[1,2]

Comments

For the engine of a hybrid running at a constant speed, the resonant frequencies of the various components of the car would be different from that of the engine and the noise level will be reduced With a background noise level of 65 decibels, the power pack would be inaudible at a distance of 10 metres.[1]

References

1 Architect or bee ? The human price of technology, Mike Cooley, Rev ed , Hogarth Press, London 1987

2 Energy for motor vehicles, Deborah L Bleviss and Peter Walzer, Sc Am , September 1990, p103

Stratified charge engine

Description

This is an example of advanced internal combustion engine There is a precise fuel injection in these engines which creates a rich mixture of fuel and air near the spark plug so that the spark can cause ignition, and it creates a lean mixture elsewhere in the combustion chamber.[1] Once the flame front is established in the rich mixture zone, it spreads throughout the rest of the chamber, even though the mean mixture strength is far below the level at which this would be possible. An advanced stratified charge engine would have spray characteristics tailored with load and reduce cycle to cycle variations and control for high unburnt hydrocarbon emission.[2]

Status

Stratified charge engines are receiving renewed interest in Japan [1]

Efficiency

These engines have efficiencies comparable to diesel engines [2]

Conservation potential

They are expected to reduce fuel consumption by one-fifth compared with the conventional gasoline engine.[1]

Environmental performance

These engines cannot meet the toughest emission standards because the oxygen rich exhaust prevents the reduction of NO_x to molecular nitrogen.[1]

References

1 Energy for motor vehicles, Deborah L Bleviss and Peter Walzer, Sc Am, September 1990, p103

2 Energy efficiency and global warming, Alan J Streb, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 87–113

Fuel injected two-stroke engine

Description

In a conventional piston ported in two-stroke engine, a large portion of the fresh charge (fuel–air mixture) gets short circuited through the exhaust port without participating in the actual combustion. This basically stems from the fact that during some interval of the intake stroke, both the transfer and the exhaust ports are open, thereby providing a path for the fresh mixture to directly go out of the exhaust leading to fuel loss and emission of unburnt hydrocarbon Retrofitting the existing two-stroke engine by a fuel injection system will eliminate this problem. This involves injecting the fuel into the combustion chamber at a time when both the transfer and exhaust ports are closed, thereby preventing the loss of fuel through the exhaust passage.[1]

Status

The technology for low pressure fuel injection two-stroke engine is commercially available.

Conservation potential

Retrofitting the existing engines with the fuel-injection system is estimated to lower the specific fuel consumption by 20%.

Environmental performance

One of the main concerns for two and three wheelers powered by two-stroke engines is the abnormally high level of unburnt hydrocarbon emission. This will be practically eliminated in the fuel-injected system.

Application

For two and three wheelers.

Comments

This technology is ideally suited for India where there is a large fleet of two-stroke powered vehicle.

Reference

1 Communication with Mr Somnath Bhattacharya, TERI, New Delhi

Low heat rejection (LHR) engine

Description

In a modern internal combustion engine of automotive size, about 30–40% of the fuel energy is converted into useful work The rest is evenly divided between the exhaust stream and the heat rejected to the coolants. The emergence of structural ceramics offers the possibility of designing a compression ignition engine that is intended to reduce substantially the heat rejected to the coolant. Such a design most often lacks the conventional water cooling system and radiator. A major share of the conserved heat, however, appears in the exhaust stream So, to capitalize on the efficiency potential of the LHR engine, it is essential to add an exhaust gas turbocharger to recover this energy Turbocharging also helps to overcome the drop in volumetric efficiency of the LHR engine, due to hotter intake manifold and cylinder wall [1]

Status

The concept of LHR diesel has drawn the attention of diesel engineers for over a decade but commercial success is yet to be realized. Among the major issues that need to be tackled are the problems related to engine tribology and the development of low cost ceramic components

Conservation potential

For achievable levels of adiabaticity, fuel consumption benefits in the range of 3–6% have been projected for turbocharged and turbocompounded heavy duty LHR diesels

Environmental performance

CO emission levels are generally low in LHR. There is, however, an increase in the NO_x due to higher combustion temperatures. NO_x can be reduced by retarding the injection timing. This, in turn, would have a negative effect on hydrocarbon emission. Refining of the LHR fuel injection and combustion systems is necessary to satisfy the emission regulations.

Reference

1 Communication with Mr Somnath Bhattacharya, TERI, New Delhi

Gas turbine engine

Description

Gas turbine engines used for automotive applications are similar to the gas turbine used for power generation [1] The turbine is designed to produce a useable torque at the output shaft.[2]

Conservation potential

Ability to use alternate fuels will reduce petroleum product consumption.[1]

Efficiency

Fuel efficiencies would be 30–50% higher than conventional heat engines.[1]

Environmental performance

Ability to use alternative fuels that emit less CO_2 will reduce CO_2 emissions.[1] However, there is emission of unburnt hydrocarbon and carbon and oxides of nitrogen which can be controlled by redesigning fuel spray nozzles and reducing cooling air to the combustion chambers to permit more complete combustion. NO_x emissions can be minimized by reducing the maximum temperature in the primary zone of the combustors.[2]

Application

This engine is being used in aircraft, automobile, and trucks [2]

Comments

Gas turbine engines will require lower maintenance Use of ceramic turbine engines will ensure a higher operating temperature.[1]

References

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2 Fundamentals of Air Pollution - Second edition, Arthur C Stern, Richard W Boubel D Bruce Turner, Donald L Fox, Academic Press Inc , 1984, p426

Methanol-powered automobiles

Description

Methanol contains only about half the energy in gasoline and diesel fuels for the same volume. So, the other things being the same, the fuel tank will have to be larger and heavier. But methanol-fuelled cars can be more efficiently designed thereby reducing the amount of fuel required.

Methanol-fuelled car will have a direct injection, turbo-charged engine. Lower heat loss will enable the removal of the cooling fan and the radiator specially if the engine walls are lined with ceramics. The car will, thus, weigh less and it can be redesigned to reduce the aerodynamic drag. Reduction in weight would make it possible for the car to have lighter frame, suspension system, brakes, and wheels. In addition to these, the car will be equipped with a variable flow hydraulic motor pump for braking, continuous transmission gears, dual clutch, computer controlled fly-wheel that prevents "idling", stops the engine and consumption of fuel and instead stores energy when the car is waiting say at a traffic signal or before starting. The car could also have a dissociator between the fuel tank and the engine where the heat from the exhaust gases can be used to decompose methanol into CO and hydrogen, which can then be sent to the engine for combustion.[1]

Status

Tests on early prototypes of methanol fuelled vehicles have been carried out at the EPA, USA. R & D work is in progress to build the more efficient models [1]

Efficiency

Tests carried out at EPA show that early prototypes of methanol fuelled vehicles will be 30% more efficient than the best gasoline engine technology [1]

Environmental performance

Owing to absence of carbon–carbon bonds in the fuel, there will be more complete combustion, lesser emissions of hydrocarbons and consequently, less photochemically produced ozone, less CO, and particulates in the form of soot [1]

Comments

The other alternatives to gasoline and diesel fuels are CNG (compressed natural gas), liquified petroleum gas, ethanol, and electricity. CNG must be kept under very high pressure. It requires a set of heavy tanks, so the vehicle performance and fuel efficiency

tends to decrease. Liquified petroleum gas has limits on supply. Electric vehicles have limitations because of the weight of batteries and the need to recharge them Ethanol is currently used as gasoline supplement but is much more expensive Inspite of the advantages cited, methanol fuels on combustion produce twice as much the carcinogenic formaldehyde than gasoline. It is corrosive, highly toxic, and has a nearly colorless flame. These call for the use of stainless steel, polyethylene or other non-corrosive material for the methanol car, flame arrestors in the opening of the fuel tank to prevent the accidental ignition of methanol vapour,and fuel additives to render some colour to the flame for visibility.[1]

Reference

1 The case for methanol, Charles L Gray, Jr, and Jeffrey A Alson, Sc Am, November 1989

CNG-powered vehicle

Description

A bank of high pressure CNG cylinders are placed in the boot (of a car), which are connected to a gas manifold which, in turn, is connected to the engine through a high pressure pipe and a gas induction device The gas induction unit essentially consists of a system of pressure regulators with a vacuum controlled metering and proportioning device for supplying gas in appropriate required quantities with preset air-to-fuel ratios The engine can be operated on either CNG or gasoline and the switching is instantaneous [1]

Status

The description given above corresponds to India's first prototype of a CNG-powered vehicle developed by IIT (Indian Institute of Technology) and PAL (Premier Automobile Limited).[1]

Elsewhere in the world, there are around 500 000 CNG powered cars [2]

Cost

- Investment for the commercial CNG car–$0 245/skm/year
- Variable O & M cost–$0 0043/skm [2]

Efficiency

The commercial CNG car uses 0 5 MJ/skm.[2]

Environmental performance

CO_2 emission from the commercial CNG car is 28.3 g/skm.[2] For the Indian prototype, unburnt hydrocarbon and CO emission levels are 180–220 ppm and 0.1–0.5% respectively, compared to the corresponding figures of 600–700 ppm and 4.45% for a gasoline-powered car.[1]

Applications

In vehicles like buses and cars.

Comments

The development of this retrofit modification kit is done in a way so as to minimize the disturbance caused to the gasoline operation capabilities of the vehicle. Drawbacks of CNG as a fuel such as lower flame velocity and higher ignition energy requirements are taken care of by adjusting the setting parameters. There is marginal loss of power near the maximum speed point which is of little consequence in intra-city driving.[1]

References

1 Natural gas powered vehicle launched, Indian Express - December 26, 1992, p2

2 User's Guide to CO_2 Database - Technology Database Version 1 0, IIASA

Efficient windows

Description

Originally, windows were made from a single layer of glass. Although glass is tranparent and capable of blocking wind, it has high emissivity and poor insulation. A traditional single pane window has a thermal resistance (R) value of 1. After the 1940s, factory-made double-glass windows, known as thermopanes, were developed. These have two glass sheets separated by a quarter-inch air space and have a R value of 2.

Some manufacturers have now designed Low-E (low emissivity) windows with insulation levels or R values from 3 to 4. In these windows, a low-E coating is applied to the inside surface of the glass facing the sealed air space. The low-E coating reflects radiant heat back into the building rather than transmitting it outdoors. A second low-E film and substitution of gases different from air like the non-toxic argon between the two glass sheets achieves further insulation.

Current efforts are directed at developing super windows with R ranging from 6 to 10 These highly efficient windows contain either vacuum or an insulating material like aerogel between the space of a low-E window.[1,2]

Status

All major US manufacturers make only low-E windows.[2] Efforts to develop superwindows is hampered by limited funding in the US.[1]

Cost

- Average cost of a low-E coating plant – $5 million.[2]
- Annualized capital – $0.1.
- Life – 20 years.
- Simple payback – five years.[3]

Cost of superwindows may be 20–50% more than that of conventional windows but reduction in fuel bills make the payback period less than four years.[2]

Conservation potential

Approximate thermal conductance of different window types is given below in units of cal(second)$^{-1}$(metres)$^{-2}$(°F)$^{-1}$:[1]

single glass – 0.83;
conventional double glass – 0.38;
low emissivity double glass – 0.26;
argon double glass – 0.15; and
superwindow – 0.08.

Low-E windows produced by a plant everyday will save 10 000 barrels of oil and an amount equal to 10 000 barrels a day offshore drilling platform which costs $500 million.[2] Annual energy savings (cal/unit) per area in square metre – 1 358 × 10^8. Net saving/unit ($/year) – 0 2.[3]

Application

In the residential and commercial sector.

Comments

At night, superwindows, according to field tests, lose a little more energy than a highly insulating R-19 wall, but during the day even a minimum amount of sunlight is sufficient to turn these windows into an energy provider. They resist condensation and block ultra-violet radiation that fade the colour of furnishing and they also provide greater thermal comfort [2]

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1 Boosting US energy efficiency through federal action, Eric Hirst, Environment 33(2), March 1991, p7

2 Energy for buildings and homes, Rick Bevington and Arthur H Rosenfeld, Sc Am September 1990, p77

3 Greenhouse warming - comparative analysis of nuclear and efficiency abatement strategies, Bill Keepin and Gregory Kats, Energy Policy, December 1986, 538-561

Efficient lighting

Description

Lighting is the second largest consumer of energy in commercial buildings and its efficiency can be improved a lot.[1] It consumes about 30% of the energy in the residential and commercial sector [2]

In conventional IB (incandescent bulbs), 70–80% of the electrical input is radiated as heat. By heating the tungsten filament to temperatures higher than the average 2700 °C, the IB emits more of its energy in the form of shorter and visible wavelenghths, but this also reduces its life A kind of new efficient IB recycles its own previously wasted IR (infra-red) energy. This is done by a thermal blanket that redirects the reflected IR radiation. Dielectric interference filters in the form of coatings made by depositing alternate layers of materials with low and high refractive index are used to achieve the thermal blanket. These coatings retain the IR and transmit the visible radiation. Each layer is about 100 nm thick and uniform to an accuracy of about 0.2 nm over the curved surface of the IB. The technique is repeatable to obtain constancy of colour, brightness, and efficiency This has been done by varying the standard chemical vapour deposition techniques Alternate layers of metal oxides have been used and the shape of the bulb has been altered to focus the IR radiation back into the filament.[3]

IB can be replaced by FL (fluorescent lamps) and CFL (compact fluorescent lamps) High pressure sodium lamps can replace mercury vapour lamps. CFL are low power FL. HID (high intensity discharge) lamps and electronic ballasts can be made use of Daylighting can be employed to adjust the light level to allow for daylight [4–6]

Status

Chemist John Ackerman and chemical engineer Himanshu Vakil at General Electric R & D Center have innovated the efficient IB. The first commercial lamp came out in 1990 and a new family of lamps known as Halogen IR PAR 38 lamps is now available in spot and flood versions [3]

CFL are commercially available and in use in USA, Western Europe, Japan, and several south-east Asian countries. Electronic ballasts are available in the USA but are not available in the developing countries in a wide range.[7 8]

Cost

- Average 75 watt IB costs about $0.6.[9]
- Replacement of IB by FL – payback period 1.1–2.3 years [10]
- Retail price of CFL – $10/piece for a 10 watt lamp including choke, at least $14/piece for an 18 watt lamp.[6,9]

For an electronic ballast:[8]

- life – 10 years;
- annualized capital – $1 7, and
- simple payback – 2 years.

Conservation potential

Reduction of energy use up to 75% is achievable by replacing IB by FL. CFL consumes 75–85% less electricity than IB. More efficient lighting will also reduce energy use for air-conditioning by limiting the amount of heat radiated from bulbs.[10 11] Installation of efficient IB and use of lighting control systems reduces electricity demand by 10–23%. Employment of daylighting lowers electricity consumption by 7–17%.[5] High frequency ballasts can provide savings of 20% or more Additional improvements from advanced luminaries, reflectors, optical sensors, and controls can increase savings up to 50%.[2 4]

Installation of efficient FL in India will cost one-sixth of the cost of building new power plants. Efficient FL give light at the same intensity and consume only about 20% of electricity (16 instead of 75 watts) [5] If 20 watt FL (with 5 watt consumption at the choke) replaced all IB (average wattage 65 5) domestic and commercial locations in India, savings will be 4167 MW at end use, 5000 MW at generation point, equivalent to 8726 MW of installed capacity assuming a thermal plant availability factor of 0 573 at peak load times Assuming the rate of investment in generation, transmission, and distribution to be Rs 1.2 crores/MW of installed capacity, the savings to the economy in terms of the reduced investments in the power sector to meet peak demand will be Rs 10 471 crores. This is based on a retail price of Rs 80/unit for the best quality 20 watt FL, including the cost of the choke and the filter.[6] If CFL is produced in India and used instead of IB, 5159 MW will be saved at the end-use point, 6191 MW at the generation point equivalent to 10 804 MW of installed capacity and save the economy Rs 12 965 crores [6]

An efficient 60 watt IB can provide the same amount of light as a 150 watt ordinary IB while consuming 60% less energy.[8] A high efficiency IB saves about 100 kWh/year at an additional cost of $12, resulting in a unit incremental capital requirement of about $0.12/kWh of end-use energy saved.[12]

For electronic ballasts, the annual energy saving is 100 KWh and net saving is $5.8/year.[8]

Environmental performance

If India switched half of its current inefficient FL by efficient FL over the 90s, CO_2 will be cut by 17 mt (million tonnes)/year which is about 3% of India's CO_2 emission of 1987 [5]

Comments

At 230 volts, IB have a lifetime of 1000 hours; at lower voltages the life is longer High efficiency chokes are important for FL for poor quality can result up to 25% of the energy consumed by the FL.[6] A 18 W CFL has a life of about 8000 hours.[9]

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5 Slowing global warming and sustaining development, Gregory H Kats, Energy Policy 18(1), Jan/Feb 1990, 25–33

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7 Access to modern energy technologies and their transfer to developing countries, R K Pachauri, Mala Damodaran TERI, New Delhi, sub DIESA/DRPA, United Nations, 1991

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9 Electricity end-use efficiency, Genevieve McInnes and Eric Unterwurzacher, Energy Policy 19(3) April 1991, 208–216

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12 Energy-technology efficiency-improvements capital requirements, energy-cost savings and global CO_2-emissions reduction, Oliver S Yu and Edwin M Kinderman, Energy 16 (11/12), 1991, 1503–1517

Space heating

Description

A building comprises of two sub-systems, the shell and the heating system in which efficiency can be improved. In case of a building shell design and wall insulation improvements; window treatments; improved heat recovery and transfer, electronic indoor temperature control; passive solar installations; proper operation and maintenance; and use of heat pumps will help to make space heating efficient.[1–3]

Status

Improved windows, walls, and heat pumps are being developed and used in the US.[1–3]

Cost

Residential absorption heat pump.

- Life – 20 years.
- Annualized capital – $71/year
- Simple payback – 2.4 years.

Advanced electric heat pump.

- Life – 15 years
- Annualized capital – $133.
- Simple payback – 3 2 years [4]

Conservation potential

Efficient space heating in the US will have a saving potential of 57.4 exajoule of primary energy by 2050 AD [3] These efficiency measures are estimated to provide a total saving potential of about 70% compared with energy-use at mid-1970s energy efficiency levels by 2050 AD.[2] Projected percentage of energy saved with improved technology compared to the best technology of 1986 in the 1990s for gas based space heating is 0–67% equivalent to 300–500 kWh/year of energy saving potential [5 6]

Environmental performance

19 73 84 000 tonnes of CO_2 will be saved in 2050 AD if efficiency improvements in space heating are introduced.[2]

Application

Space heating accounts for more than 50% of the energy consumed in the residential and commercial sectors in the US.[2]

References

1 Potential energy savings from efficient electric technologies, Clark W Gellings, Ahmad Faruqui, Ken Seiden, Energy Policy 19(3), April 1991, 217–230

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Water heating

Description

Improved water heating systems include low-flow devices, insulation, improved oil and gas burners, and valves that reduce convection losses and temperature reductions. Heat pump water heaters and heat recovery systems and cogeneration systems can also improve the efficiency of water heating. Integrated heat pump systems can meet space heating, cooling, and water heating requirements simultaneously.[1,2]

Status

Improved water heating systems are being developed and used in the US.[3]

Cost

Heat pump water heater

- Life – 8 years.
- Annualized capital – $83/year
- Simple payback – 2.4 years.[4]

Efficiency

Compared to conventional oil and gas burners with 70–80% efficiency, combustion efficiencies up to 95% can be achieved with the liquid and gas fuelled pulse combustors.[2]

Conservation potential

Projected percentage of energy saved with improved technology of 90s compared to the best technology of 1986 for gas and electricity based water heating is 33–100% and 7–60% respectively equivalent to 100–150 and 1000–1500 kWh/year of energy saving potential respectively [3,5]

Studies have shown that a heat pump water heater uses 50% less energy than an electric resistance water heater [6] Annual energy savings using heat pump water heaters will be 2800 kWh and net saving will be $141/year [4]

Estimated annual energy saving potential with improved water heating in 2050 AD will be 7.9 exajoules.[2] Overall savings on water heating can range from 40 to 60% [1]

Environmental performance.

CO_2 saved with technology improvement in water heating will be 2 27 20 000 tonnes in 2050 AD [6]

Application

In the residential and commercial sectors

References

1 Potential energy savings from efficient electric technologies, Clark W Gellings, Ahmad Faruqui, Ken Seiden, Energy Policy 19(3), April 1991, 217–230

2 Energy efficiency and global warming, Alan J Streb, Presented at the IEA/OECD Expert Seminar on "Energy Technologies for Reducing Emissions of Greenhouse Gases", Paris, France April 12–14, 1989, 87–113

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Refrigeration and air-conditioning

Description

Efficient refrigeration and air-conditioning can be achieved by better insulation, compressor, fan motor or by adding a new compressor.[2,8] Improved compressors have multiple unequal parallel systems, advanced compressor cycles, and variable speed controls. Evaporatively cool condensers, floating head pressure systems, air barriers, food case enclosures, control and maintenance practices can make refrigerators more efficient.[1] Refrigerators with large freezer sections could be equipped with a separate compressor for the freezer circuit.[2] A strict maintenance routine, which includes replacing filters and cleaning coils in the air-conditioning system and rescheduling the operation of individual chillers according to the time of the day and the outdoor temperature, sharply increases the efficiency of air-conditioning systems.[3] Improved thermodynamic performance of the refrigeration cycle is effected through the use of new non-azeotropic refrigerant mixtures instead of pure CFC fluids.[4]

Status

Average US refrigerators use 1300 kWh/year. Best commercially available model in the US uses 750 kWh/year. Average size of an American refrigerator is 500 litres.[5] Most efficient refrigerator freezers use about 200 kWh/year which is about 15% of the average use.[6] Efficient Indian refrigerators use about 700 kWh/year.[7] However, average capacity of Indian refrigerators in use is about half that of its American counterpart

Cost

It will cost $0.02/kWh saved to reduce electricity consumption by 80% in refrigerators.[8]

High efficiency refrigerator compressor

- Life – 17 years.
- Annualized capital – $1/year.
- Simple payback – 1.1 year.

High efficiency refrigerator/freezer.

- Life – 17 years
- Annualized capital – $10/year.
- Simple payback – 4.5 years [9]

Conservation potential

Projected percentage of energy saved with improved technology compared to the best technology of 1986 in the 1990s for room air-conditioners, central air-conditioners, refrigerators, freezers are 25–67%, 20–50%, 50–150%, and 43–115% respectively, equivalent to 300–400, 1200–1500, 300–500, 200–300 kWh/year of energy saving potential respectively. [6,10]

Annual energy savings using an efficient refrigerator compressor will be 152 kWh and net saving will be $12/year.[9] Annual energy savings using an efficient refrigerator freezer will be 280 kWh and net saving will be $13/year [9]

Environmental performance

Use of new nonazeotropic refrigerant mixtures can reduce the ozone depletion caused by conventional refrigerants.[4]

Application

In the residential and commercial sectors.

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Appliances

Description

Appliances include cooking stoves, ranges and ovens, washing machines, clothes dryers, computers, fax machines, etc.

- Use of well-designed stoves and/or gasified biomass can be adopted for cooking.[1]
- Improved electrical cooking include better insulation, reflective pans, reduced thermal mass, and less contact resistance [2]
- Efficiencies in appliances like washing machines, elevators, and escalators can be improved by the integration of electronic control devices and use of efficient motors.[3,4]
- Use of C-MOS instead of N-MOS chips in microelectronics reduce energy consumption.
- Introduction of liquid crystal, gas plasma or electroluminiscence flat screen displays replacing conventional cathode ray tube type screens in the computer will reduce energy consumption.
- Use of laptop computers with automatic switch to go over to low power mode reduces the power consumption of the screen when the terminal is not in use for extended periods of time.
- Improvements in printing and photocopying devices can be achieved with the use of ion deposition technology and cooled compression rollers which use only pressure instead of the conventionally used heated drums which employs both heat and pressure to fuse the toner to the paper.
- The need for hot water can be eliminated by the use of special detergent; the chemical and mechanical action can be separated; use can be made of ultrasonic vibration for cleaning and microwave for drying in the washing machine.[3]

Status

Efficiencies of appliances are being improved worldwide.

Efficiency

Efficiency in electrical cooking appliances ranges from 20–30%.[2] Efficiency of well designed stoves is about 50%. Gasified biomass used in a gas stove has 80% efficiency.[1,5]

Conservation potential

Projected percentages of energy saved with improved technology compared to the best technology of 1986 in the 1990s for electric range, gas range, electric clothes dryer, gas clothes dryer are 40–75%, 33–60%, 60–220%, and 0–17% respectively, equivalent to 400–500, 25–30, 250–500, kWh/year (figures for gas clothes dryer are not available) of energy saving potential respectively.[6,7] Well designed stoves use about 25% of the energy consumed in open fire cooking.[5] C-MOS chips use 30–40% less energy than N-MOS chips. Conventional computer screens use 25–50 W whereas liquid crystal, gas plasma or electroluminiscence consume only 7–10 W.[3]

Application

In the residential and commercial sectors.

Comments

Computers, fax machines, and other electronic goods will contribute significantly in the energy use in the years to come. Recent studies in north-eastern US indicate that the growth in energy demand attributable to additional electronic equipment is 1%/year [7]

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Irrigation pump sets

Description

An electricity or diesel driven device that pumps water from underground.

Status

Pump sets find widespread use in India. There are 8 9 million electric pumps and 7 5 million diesel pumps in India [1,2]

Cost

The average cost per pump set in India is Rs 1000
Payback period – 14 months.[1 2]

Efficiency

Average efficiency of pump sets in India is 25–30% The maximum achievable efficiency is targeted at around 55% [3]

Conservation potential

Diesel pumps consume 7 5 billion litres of HSD and electric pumps consume 40 billion kWh electricity annually Replacement of high friction suction line and foot valve of centrifugal pump by low friction suction line and foot valve could conserve 20% energy. Similar changes in the delivery line leads to a conservation up to 30%. In addition to these improvements, replacement of an inefficient pump by an efficient one would conserve 40% energy A complete replacement of an existing system by the most efficient system could conserve up to 50% energy.[1 2]

Application

Pump sets are used in the agriculture sector for purposes of irrigation.

References

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2 Low cost and quick measures for energy conservation in agriculture, S M Patel, TIDE 1(4), 1991, p25

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Turbine-driven centrifugal pump

Description

Steam is expanded in a back-pressure turbine to drive a centrifugal pump The turbine is used as a prime mover for the pump. It also helps to provide process steam requirements [1]

Status

Introduced in a fertilizer plant in India in 1978 [1]

Cost

Investment of the order of Rs 14 4 million [1]

Conservation potential

Saves the energy that would otherwise be wasted in throttling of the order of 5 1 kWh.[1]

Application

Replacement for electrically driven reciprocating carbamate pumps in Urea plants in the fertilizer industry.[1]

Comments

Money saved in Gujarat State Fertilizer Ltd by using turbine driven centrifugal pump instead of electrically driven reciprocating carbamate pumps was Rs 5.1 million at current prices in 1987.[1]

Reference

1 Energy conservation in fertilizer plants, Industrial Energy Conservation - Case Study Series 2, Gujarat State Fertilizer Co Ltd, TERI, March 1987

Heat pumps

Description

Heat pump is a heat engine in reverse. It requires a work input to deliver heat from a lower temperature to a higher temperature [1] The source of heat can be industrial waste heat from water, steam or some vapour as used in industrial heat pumps, ambient air as often used in space heating or heat in the food which is extracted by the refrigerator which is also a heat pump.[1,2]

There are mainly two types of heat pumps.

(1) Vapour compression heat pump (VCHP).

(2) Absorption heat pump (AHP)

VCHP has a prime mover which could be electrically or mechanically driven by a motor or engine VCHP may be an OC (open cycle) or a CC (closed cycle) heat pump In an OC, the vapour or waste gas at a lower temperature or pressure is compressed directly mechanically to a higher temperature and pressure to attain a useful process level and then recycled Substantial energy saving results in the process because the energy needed to compress the vapour is only a small fraction of the energy that would be required to generate the vapour at the same pressure and/or temperature in a boiler [4,5] In a CC, the heat is extracted from the heat source in an evaporator isothermally and the refrigerant is vaporized. These vapours then go to the compressor where high temperature and pressure are achieved Heat is transferred from the condenser isothermally as vapours condense and the refrigerant changes to liquid form. Liquid refrigerant then expands in an expansion device adiabatically and then is recycled back to the evaporator at a lower temperature and pressure.[1]

Unlike the VCHP which is driven mechanically, the AHP is driven by heat In the AHP, the refrigerant absorbs low grade heat, vaporizes and is then absorbed by a solvent (as in LiBr water) and is compressed in an absorbed state till the temperature and pressure of the mixture is equal to that of the heat generator The vapour is then desorbed, condensed, and recycled.[1 3 4]

Status

In West Germany, a total of some 750 VCHP installations driven by gas engines are presently in operation, covering a heat demand of nearly 900 MW [5] Low energy housing for cold countries with heat pumps using natural gas were designed and built in UK and their prototypes installed.[6]

Heat pumps are used in dairy, distillaries, timber drying, and fertilizer plants in India.[7]

Cost

- Capital cost of VCHP – \$300–600/kWh
- Operational cost – \$4000/year excluding fuel cost [8]

Efficiency

OC VCHP is more efficient than CC VCHP Energy required by heat pumps to produce heat is less than the energy required for direct heating, thus efficiency is higher than 100% since useful heat delivered is more than the primary energy input [2]

Environmental performance

CC VCHP uses refrigerants like CFCs which cause damage to the ozone layer AHP does not use CFCs but mixtures like LiBr-water which are environmentally safer It does not make any noise.[1,5]

Application

For space heating, cooling, and refrigeration in the residential and commercial sectors For waste heat recovery and drying in industries [1 8]

Comments

Natural gas driven VCHP saves more energy than the electrically driven ones because transmission and distribution losses accrue to the latter.[6]

In AHP, LiBr water when used at medium or high temperatures accelerates the corrosion of equipment Recently both water–nitrate salt and a nitride complex solution have been found which are not so corrosive at high temperatures [5 9]

Heat pumps are most effective when the temperature boosting is small, i e , when the objective temperature is close to the temperature of the waste heat [5]

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Humid air turbine air-conditioner

Description

HAT (Humid air turbine) first dehumidifies air with a desiccant The dehumidified air is subsequently cooled to achieve air-conditioning In one approach, the air being conditioned is passed through one segment of a rotating wheel, where a solid desiccant removes the moisture from the air stream. The wheel is then rotated continuously so that a stream of heated air can be passed through the saturated segment, extracting the moisture by evaporation The regenerated wheel can pick up the moisture again. The hot air containing the moisture is exhausted to the outdoors The moisture capture by the desiccant causes the heat of condensation to heat the wheel. The dry air is usually required to be cooled even if the ambient temperature is satisfactory Cooling is typically accomplished with a substantially smaller vapour compression cooling system [1]

Status

Emerging technology in the US [1]

Conservation potential

Effective dehumidification prevents the condensation of excess moisture on cooling coils of refrigeration and thereby reduces energy and fuel consumption over and above its characteristic consumption which itself is lower than conventional air-conditioning system.[1]

Application

Desiccant-based cooling system is suited for supermarkets in the commercial sector where humidity control has a higher priority than temperature.[1]

Comments

The comfort of air-conditioning results from dehumidification that accompanies the actual cooling of air In a conventional system, this is an extremely energy intensive process because the air is first overcooled to below its dew point and then reheated to the desired temperature level In a HAT air-conditioning system, the cooling of air below its dew point is not required [1]

Reference

1 Changing prospects for natural gas in the United States, W M Burnett and S D Ban, Science 244, 1989, 307–310

Variable speed drives

Description

The most common form of a VSD (variable speed drive) is a semiconductor rectifier that creates a simulated alternate voltage composed of square pulses of modulated time width [1] The strategy employed is to reduce the input voltage at low load requirements to reduce the power consumption.[2]

Status

In the US, VSD is being used in industrial applications where motor use is significant over the year, as a result, the required speed varies and the horse power requirement is high.[3]

In developing countries like India, though the technology and design capability exists, the prohibitive cost involved is the major drawback to the widespread commercialization and use of VSD [2]

Cost

For a potential saving of 5.55×10^{13} calories in 2000 AD and $7\ 57 \times 10^{17}$ calories in 2010 AD through the use of VSD, estimated levelized cost is 19 cents/million calorie [3]

Conservation potential

Motor drive systems like fans and pumps often need to vary their output to accomodate process needs or load variations This used to be originally done by running the motor at full speed while throttling its output by a partly closed valve or damper Electronically adjustable speed drives can reduce this type of energy waste [5] Energy savings range between 20 and 50%.[4]

Application

In motors used in the industrial, transportation, residential, commercial, and agriculture sectors

Comments

AC VSD is increasingly being used for application requiring speed control that had traditionally been the domain of DC speed drives [2]

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Electric motors

Description

Electric motors are used to provide motive power to equipment such as compressors, pumps, and blowers [1] The efficiency of a motor is the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at the terminals The efficiency with which this transformation takes place is determined by the intrinsic losses occuring within the motor. These losses can be reduced only by changes in the motor design. Intrinsic motor losses consist of no-load or fixed losses (magnetic core losses—eddy currents, hysterisis losses in the stator and rotor magnetic structure) and load or variable losses. Fixed losses also consist of friction and windage losses Motor performance is also affected by voltage imbalance across the three phases and voltage variation. Rewinding of burnt out motors can also be detrimental to the motor efficiency due to poor workmanship and rewinding practices [1]

Energy efficient (EE) motors are better designed and made from higher quality materials compared to that used in conventional motors, thereby reducing the mechanical, magnetic, and resistive losses appreciably [2] Losses can be reduced by using

low loss steel, increasing the active material by incorporating a longer core length, using thinner laminations, reducing the air gap between the stator and the rotor, using copper bars in the rotor instead of aluminium, using superior bearings and smaller fans.[1]

Status

EE motors are found in North America, Western Europe, and Japan [2] EE motors also find industrial application in India [1,3]

Cost

EE motors cost about 30% more than the conventional motors.[1]

Cost of a 15 kW EE motor in India – Rs 35 225 as on 1 October, 1991.[4]

Payback period is dependent on several factors, namely, extent of achievable saving by replacement of an ordinary motor by an efficient one and the existing tariff structure It could be up to five years for a 15 kW EE motor [4]

Efficiency

EE motors are 2–5% more efficient than standard motors [5] Efficiency of a two-pole 15 kW EE motor is 91% at full load, 90 5% at three-fourth load, and 89% at half load; for a four-pole the corresponding figures are 91 5%, 91%, and 90%, for a six-pole they are 90%, 90%, and 89% respectively.[4]

Application

Used for motive power in the industrial, commercial, residential, transportation, and agriculture sectors.

Comments

Motors operating for less than 2000 hours/year are not good candidates for replacement by EE motors EE motors are also not suitable for multi speeds, frequent starts and stops, very high inertial loads, and for low speed motors (less than 720 rpm) [1]

Motors require proper lubrication for reducing friction and clean cooling ducts for proper ventilation and dissipation of heat. Other options for reducing motor electricity consumption are use of multi-speed motors, delta-star changeover switch and flat belt transmission drives.[1]

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Production of steel

Description

The production of steel involves a number of steps Iron ore is first reduced to pig iron in a blast furnace using coke as the primary fuel, or directly reduced to sponge iron The ore is usually processed before being reduced in a blast furnace either by being shaped into pellets or by a process called sintering. The pig iron from the blast furnace is further purified into steel in an OHF (Open Hearth Furnace), a BOF (Basic Oxygen Furnace) or in an EAF (Electric Arc Furnace) which are the main ways of making steel The crude steel is then either moulded into ingots or is directly cast into shapes such as beams and bars The steel is then finished by rolling, annealing, pickling, coating or other treatments.[1]

OHF are reverbatory furnaces for making steel. External heat is supplied by burners in order to melt the charge for the steelmaking process OHFs are fired by either gaseous or liquid fuels in integrated works, they are usually fired by coke oven and blast furnace gases [2]

In a BOF, oxygen is blown in through molten metal that burns most of the carbon present The precise level of oxygen can be adjusted as desired and the heat generated inside the metal by the burning supplies the energy to remove other impurities in the form of slag [3] Since BOF is not a melting unit, it cannot handle large quantities of solid steel scrap in the charge [2]

EAF mostly melts and processes scrap steel Scrap beneficiation techniques are often required to remove residual elements from scrap steel prior to their use as EAF charge.[1]

Direct steelmaking from ore would involve continuous desulphurizing and decarburizing of the melt till it would be ready for treatment at the ladle station before casting. In a direct steelmaking process, powdered ore, coal, oxygen, and flux are blown into the converter which contains a bath of molten iron. The iron oxides are reduced to iron and the impurities are driven off in the form of slag.[1,3]

Ore to powder steelmaking involves the conversion of ore to iron powder that does not require melting. One approach requires initial reduction, magnetic separation, and chemical leaching. The product is dried and further reduced, then separated magnetically to produce a powder that can be rolled into steel products

The Plasma arc steelmaking process requires generating a stable arc between two electrodes The high temperatures generated in the plasma increase the heat transfer for melting the scrap.[1]

Most of the steel produced is cast into ingots, allowed to cool, then reheated for rolling and casting into semi-finished products such as slabs, blooms, and billets However, some of the steel is directly and continuously cast into semi-finished products from EAF or BOF Continuous casting methods include thin slab casting, thin strip casting, and spray form casting. Thin slab casting produces a slab greater than 2 cm thick, so the rolling necessary to produce a thin slab is reduced Thin strip casting produces a strip less than 2cm thick and allows the elimination of the hot rolling step Spray form casting deposits a spray of liquid metal onto a surface to produce a sheet even thinner than that produced by thin strip casting eliminating the hot rolling step [1 4]

Status

OHF are not in use any more in the developed world. They, however, continue to dominate the Indian Steel industry.[3 4]

BOF is used to produce nearly two-thirds of the steel supply in the developed world [1] Some integrated steel factories in India use BOF [5]

In 1988, 31 4% of the steel produced in the OECD countries was through the EAF The portion of steel produced from scrap was 38% in 1987 and may increase to as much as 50–60% in the US.[6] Steel production in India through electric arc furnaces and induction furnaces is presently at the level of 4 mt of crude steel annually, about 25% of the crude steel production in the country These furnaces are manufactured in India by General Electric Company of India Ltd [7]

Direct reducing coal making could be commercially viable in the next ten years.[1] In Japan, R & D is being carried out under the 7-year plan which started in 1988 [8]

Progress in ore to powder and plasma arc technology for steelmaking are underway The former is hampered by the lack of effective magnetic separation techniques [1]

Continuous casting was used in 77 5% of the production of OECD steel in 1988 In India also, this method is used alongside casting steel into ingots Production of steel by thin slab continuous casting is close to full-scale commercialization Development of thin strip continuous casting is underway and will take 5–10 years to be fully commercialized.[1 5]

Cost

Capital cost of EAF in Japan – 500 million yens.[8]

Efficiency

Approximate specific energy consumption per tonne of crude steel produced

BOF – 19 GJ.[1]

OHF – twice of that of BOF.[3]

EAF – 8.5 GJ.[1]

Energy consumption in continuous casting for preheating the equipment and maintaining a steady temperature throughout the process is 0 26 GJ/t of steel Conventional socking pit operation and ingot reheating takes 1.055–2.1 GJ/t of steel [4]

Conservation potential

Improved and optimized OH furnace design involves optimizing regenerator flue size, mass-area ratio, hydrojet cleaning, and prevention of air leakage because thermal efficiency and keenness of OH furnaces is largely governed by the effectiveness of the regenerator checker work which recycles the waste heat in the form of preheated air to increase the flame temperature and, thereby, accelerate heat tranfer Oxygen enrichment of the air and the direct blowing of metal with oxygen intensify the melting process and result in up to 20% reduction in specific energy consumption.[2 3 5]

Use of EAF and continuous casting reduces energy consumption. Energy use in steel production in the US can be reduced from 21 4 GJ/t to 14 8 GJ/t by efficiency improvements like dry quenching of coke, blast furnace modifications, in-process control of temperatures and carbon content of BOF, scrap preheating in EAF, ladle injection and secondary refining, direct casting and rolling, and slab heat recovery.[1,6,8–10]

Direct steelmaking could result in 20–30% reduction in energy use Ore to powder method when commercialized would use about 40% less energy Plasma arc technology would also conserve energy by virtue of its smaller capacity (about 5 MW range) compared to 60–80 MW for EAF.[1,3]

Environmental performance

Improvement in efficiency will reduce carbon emissions. Direct steelmaking will eliminate coke ovens and related pollution.[1,3]

Comments

Specific consumption of Indian steel plants is approximately 37.6–50 GJ/t of crude steel.[5]

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Production of aluminium

Description

Aluminium is mainly manufactured by the reduction of alumina (Hall–Heroult process). In this process, a pool of molten aluminium underlies a bath of electrolyte and alumina feed in an electrolytic cell. The aluminium metal forms the cathode. The anode is made from carbon which reacts with alumina to give aluminium and CO_2.[1,2]

Aluminium can also be manufactured by Alcoa process from aluminium chloride and by sulphide electrolysis. However, the former suffers from corrosion problems and the latter creates unacceptable amounts of hydrogen sulphide.[2 3]

In carbothermic reduction processes, aluminium can either be directly reduced in an electric arc furnace or bauxite can be reduced directly without separate pyroprocessing of the bauxite ore to extract alumina [3]

The electrolytic processes can be made more energy efficient by introducing permanent anodes and wetted cathodes. One such technology involves the use of a chemically inert anode and a corrosion resistant titanium–boride–graphite cathode.[1–3]

Status

New electrolytic plants are under development in Canada and Brazil.[1] The Carbothermic processes have to undergo substantial development before they can be commercialized.[3]

Cost

Aluminium smelting costs 35.2 cents/kg in 1986 average US practice.[1]

Efficiency

Typical efficiency of the Hall–Heroult process is less than 50%.[4]
Specific energy consumption values are:[3]
Hall–Heroult process – 12.9–17.6 kWh/kg;
Alcoa process – 10–12 kWh/kg; and
Sulphide electrolysis process – 8.4 kWh/kg.

Conservation potential

Permanent anodes would eliminate the problems associated with anode changes and the use of energy intensive coke to make the anodes. Wetted cathode would save energy by reducing the voltage drop across the bath in which aluminium is reduced.

Aging contributes to increasing energy consumption in smelters. New smelters consume 13.5 kWh/kg against 20 kWh/kg of the older ones. By the year 2000, specific energy consumption can reduce to 12 kWh/kg. The theoretical limit is 6.5 kWh/kg

Recycling can reduce energy requirements to 90–95% [3]

Environmental performance

CO_2 emissions will be reduced in the new electrolytic process since it does not use carbon.[1]

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Efficient dyeing/finishing industry

Description

Dyeing/finishing industry can be made more energy-efficient by thorough maintenance and inspection, exhaust heat recovery and reuse, rational fuel combustion, introduction of less energy consuming units such as jet set dyeing machines, minimum dye liquor feeders, and counter current washing machine. Large capacity exhaust heat recovery with heat pumps is highly promising in this industry in view of the relatively low temperature used in the dyeing process [1]

Status

Used in Japan.[1]

Conservation potential

Conservation rates are as follows·
jet type dyeing machine – 70%;
minimum dye liquor feeder – 55%; and
counter current washing machine – 70%

Comments

For a jet type dyeing machine
share of given process in fuel use in entire process – 10%, and
additional conservation potential – 6 kWh/t.
For a Minimum dye liquor feeder.
share of given process in fuel use in entire process – 15%; and
additional conservation potential – 8 kWh/t.
For a counter current washing machine
share of given process in fuel use in entire process – 10%; and
additional conservation potential – 7 kWh/t.[1]

Reference

1 Possibilities of carbon-dioxide reduction in the industrial sector, Naoto Sagawa, Energy in Japan 111, September 1991, 14–24

Production of paper/pulp

Description

Paper products are made by first preparing wood and converting it into pulp. The conversion can be either done by mechanical processing, by reducing the wood to fibre, by chemically processing it or by a combination of both. After the pulp is formed, it may be bleached and formed into a mat of board, paper or pulp and dried typically by steam heated rollers.

The process that dominates in chemical pulping is the kraft or sulphate process. Paper is also made from waste paper after recycling.

Three advanced processes are biopulping, chemical pulping with fermentation, and ethanol-organic solvent pulping. All these involve integrating a fermentation process into a conventional pulping process.[1]

Status

Chemical and mechanical processes are widely used for pulping In North America, chemical processes accounted for 75%, mechanical processes 20%, and combination 5% in 1986. In the OECD countries as a whole, the corresponding figures are 72%, 23%, and 5%. Pacific OECD countries produce maximum paper from recycled waste. Recycled paper formed 48.2% of the paper produced in these countries. Corresponding figures for North America and Europe are 18 1% and 35.2% for 1986.

The three advanced processes are in the R & D stage.[1]

Cost

Conservation costs of replacing/substituting the existing specific components by energy efficient components in the Japanese paper/pulp industry are: [2]

- continuous digesters – 3 billion yen;
- displacement type continuous bleaching machine – 7 billion yen;
- efficient recovery boilers – 5 billion yen,
- oxygen bleaching facilities – 3–5 billion yen.

Efficiency

Specific energy consumption for producing a tonne of pulp (excluding the processing of wood feedstocks): [1]

mechanical pulping – 4.8 GJ (consumes more electrical energy);
chemical pulping – 1.5–5.7 GJ (consumes more thermal energy), and
recycled paper pulping – 4–5 kJ (consumes mostly electricity).

Conservation potential

Pulping is one of the most energy intensive steps in papermaking. Mechanical pulping consumes electric energy while chemical pulping consumes thermal energy.

Drying consumes about half the energy needed to produce paper. Drying after chemical pulping can be done by the steam raised by burning the lignin that is removed from the wood. Drying after mechanical pulping is done by thermal energy produced from fossil fuel. Use of hoods over the drying line to retain the heat near the paper saves considerable energy in the drying process.[1]

Energy can be conserved in the paper pulp production by:

1 making more recycled paper;
2 greater use of wood waste and spent pulping liquor;
3 use of continuous digesters;
4 use of displacement heaters in pulping;
5 improvements in spent liquor concentrations through upgraded evaporators or freeze concentration;
6 spent liquor gasification;
7 mechanical dewatering of papermaking process;
8 increased cogeneration;
9 wet pressing, vacuum removal, and dry forming techniques;
10 use of radio frequency equipments, and
11 waste heat recovery in the drying of formed paper.

In Japan, the following methods have proved useful for prevention of heat losses and exhaust heat recovery and reuse.

1 Improved insulation at dryer's edge results in 15% conservation of steam. Conservation potential – 0.7 litres.
2 Installation of coal kilns flash dryers results in 20% conservation of heavy fuel oil. Conservation potential – 2.7 litres.
3 Improved insulation of coal kilns/exhaust heat recovery results in 7% conservation of heavy fuel oil. Conservation potential – 0.9 litres.
4 Continuous digesters results in 30% conservation of steam. Conservation potential – 5.1 litres.
5 Displacement type continuous bleaching machine results in 60% conservation of steam and 50% conservation of electricity. Conservation potential – 14.1 litres and 72.5 kWh.

6 Hot presses designed for paper machines results in 8% conservation of steam. Conservation potential – 1.8 litres.

7 Liquid membrane flowing down type evaporator results in 20% conservation of steam, 40% conservation of electricity. Conservation potential – 6.7 litres and 3 kWh.

8 Rationalized combustion in the form of efficient recovery turbines result in 20% conservation of heavy fuel oil. Conservation potential – 17.8 litres.

9 Feedstock/chemical related measures like bleaching conserve 20% electricity. Conservation potential – 48.7 kWh.

10 Computerized cooking process conserves 1% steam. Conservation potential – 0.3 litres.

11 Computerized boiler turbine conserve 1% fuel oil Conservation potential – 0.8 litres.

12 Computerized paper machines conserve 1% steam. Conservation potential – 0.8 litres.

13 Strengthened counter current washing machine in bleaching machines conserve 20% steam. Conservation potential – 2.7 litres.

(All the above values are for Woodfree paper Integrated Mills per tonne of paper produced as given in reference.)[2]

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Production of soda

Description

Caustic soda is predominantly produced by elctrolysis of sodium chloride. In this process, three types of cells are used. (i) Diaphragm cells which give weak caustic liquor of about 10% which requires further concentration by steam, (ii) mercury cells which produces 50% caustic liquor, and (iii) membrane process.

Soda ash is produced either by the Solvay or by the dual process. The production steps consists of pulverizing salt, brine purification, absorption of ammonia in brine, carbonation to form sodium bicarbonate and ammonium chloride. The sodium

bicarbonate precipitate is filtered in rotary vacuum filters and calcinated in rotary calciners to obtain soda ash. Soda ash is, then, centrifuged and dried using hot air In the Solvay Process, the filtrate ammonium chloride solution from rotary filters is steam distilled with lime to recover ammonia which is recircuited in the process. In the dual process ammonium chloride is crystallized from the solution and used as fertilizer [1]

Status

For India, production and capacity utilization of caustic soda and soda ash and their plants in 1990/91 were 10 18 083 tonnes and 80.9% and 14 16 272 tonnes and 90.9% respectively.

Till 1990, about one million tonnes of caustic soda was based on the mercury process, about 1.2 lakh tonnes on diaphragm cells and about 1.3 lakhs on the membrane process.

Over the years, the Solvay process has been improved in terms of reducing energy consumption and the dual process for soda ash production is favoured for capacity addition.[2]

Efficiency

Specific energy consumption in the production of caustic soda are given below [3]
Membrane process – 2400 kWhe/t
Mercury process – 3000 kWhe/t.
Diaphragm cell – 3400 kWhe/t.

Specific energy consumption in the production of one tonne of soda ash are given below.[4] Solvay process – 15 8 GJ thermal energy, 300 kWhe.
Dual prcocess – 8.96 GJ thermal energy, 600 kWhe

Conservation potential

Technologically, Solvay process can be made more energy efficient by (i) substitution of direct rotary calciners by indirect steam tube rotary dryers for drying of soda ash, (ii) the use of larger diameter carbonating towers for absorption of CO_2 in ammoniated brine, and (iii) complete recirculation of water to minimize heat losses and the use of plate type heat exchanger

Energy efficiency of soda industries can be improved by:
(i) installing metal anodes, (ii) installation of automatic anode over potential controllers, (iii) rubberlined bottom plates changed to bare bottoms eliminating imbalances in current

distribution, (iv) installation of HT capacitors in electrical system, improving the power factor; (v) metallizing of bus bar contacts to reduce voltage drop across bars;
(vi) maintenance of high feed brine temperature and modification of brine flow systems, through water sealing of clarifiers, insulation of clarifiers, dosing chambers, and piping systems, etc., heating of feed brine with depleted brine; (vii) utilization of unused hydrogen as fuel in fusion plants and boilers; (viii) installation of preconcentrator for fusion plant; (ix) recovery of waste heat from fusion plant and HCl furnace in some case; (x) conversion from mercury cell process to ion exchange membrane cell process and thereby saving about 20% energy; and (xi) use of teflon covers for cells in place of flexible rubber covers.[1]

Environmental performance

Mercury is present in the effluent of mercury cell in caustic soda plants However, there exists a technology to remove the mercury from the effluent The diaphragm and membrane cells do not suffer from this potential hazard.[1]

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Production of cement

Description

Two basic methods of producing clinker are the wet and the dry processes, with semi-wet and semi-dry being the variations

The wet process permits more homogenization of the kiln feed and reduces the need to grind the raw materials but it is highly energy intensive because of the heat needed for pyroprocessing to evaporate the water prior to the chemical reaction that forms cement.

The dry process is technologically advanced and less energy intensive and use rotary kilns to produce clinker.[1,2]

Status

In 1990, 82% of the cement in India was produced by the dry process.[3] Cement plants in Andhra Pradesh, Gujarat, and Assam use natural gas.[4]

Countries where technology improvements in cement production being undertaken include Japan, US, and UK.[1,2]

Cost

- Plant cost – Rs 1800 crores in India in 1985.
- Variation in cost – Rs 500 crores.
- Capacity utilization – 85%.
- Production – 8.3 lakh tonnes/year.
- Estimated capital cost – Rs 350/t of cement.[5]

Efficiency

Specific energy consumption by Indian Cement industry
Dry process – 3.7 GJ fuel energy and 129 kWhe/t of clinker, and
Wet process – 6 3 GJ fuel energy and 121 kWhe/t of clinker.

Corresponding figures for the world are.
Dry process – 3.2 GJ fuel energy and 87 kWhe/t of clinker; and
Wet process – 5.2 GJ fuel energy and 110 kWhe/t of clinker
In OECD countries consumption of fuel energy ranges from 3.2 to 7 0 GJ/t of clinker. Average efficiency of kilns in the 80s was about 4 5 GJ/t of clinker in these countries as against a value of 6.28 GJ/t for older kilns.[2,5,6]

Conservation potential

In OECD countries, it is estimated that 100 MJ/t can be saved through further technology improvement in cement production, 300 MJ/t can be saved with the use of off-grade fuel, 300 MJ/t can be saved by reducing the clinker firing temperature and 100 MJ/t can be saved through the blending of secondary materials.

In the US, energy consumption in the cement industry can be reduced by 40% if all plants operated at the efficiency of the most efficient plant Such plants would be achievable by improving the grinding of the raw materials and clinker, the kiln and through the use of waste heat and waste materials (in cement blends by adding fly ash, blast furnace slag, and cement kiln dust and in fuels by adding waste oil, rubber tyres, and municipal waste).

In the UK, it is estimated that by 2000 AD, 29 6% of energy could be saved by converting from wet to dry process in cement production, kiln insulation could reduce energy use by another 2%, waste material blends could further reduce this by 2 4%, mineralizers added before kilning could lower temperatures and cut energy use by 3.3%,

improved combustion can save 5% energy and waste material as kiln fuel can reduce fossil fuel use by 4.9% over the 1981 energy consumption of 5.71 GJ/t of clinker.[2]

There are several advantages of using natural gas over high ash coal as fuel in rotary kilns of cement plants. These are particularly pertinent to India and include: (i) freedom from ash contamination and hence, scope for exploiting marginal grade limestones, implying an improvement in thermal efficiency by about 1.5%, and (ii) complete elimination of coal grinding, resulting in saving electrical energy to the extent of 7–11 kWh/t of cement.[7]

Savings from energy conservation measures in the Indian cement industry are identified as long term, medium term, and short term. In the long term, all cement will be manufactured by the dry process.

Long term measures.

The measures for the ACC cement plants [6] are given below.

(i) Separate grinding of slag and clinker instead of the present mode of grinding them together will save power worth Rs 75 million/year. (ii) Waste heat from kilns, preheater and clinker will be utilized for power generation and save Rs 87 million/year

(iii) Setting up of coal washery to separate good and bad quality coal. The good quality coal is for use in the kiln and the rejected coal is to be used in the captive plant. Existing boilers at captive plants are to be replaced by energy efficient fluidized bed boilers. This would save Rs 27 5 million/year.

Medium term measures.

(i) Dry raw milling systems are being upgraded by incorporating efficient mill internal liners, high efficiency separators, and improved mill ventilation systems that would save Rs 6 million/year. (ii) Improvements on coal mills being done by rationalization of the circuits, provision of steady heat source by the use of waste heat from clinker cooler and provision of bag filters for 100% fine coal recovery from coal mill exhaust gases will save Rs 8.5 million/year. (iii) Latest design features of mill internals in the grinding mills will save Rs 45.6 million/year. (iv) Installation of new fluidized calcinators and preheater components in dry process kilns; upgradation of clinker coolers and efficient burner pipe systems can save Rs 5 million/year, reduce fuel consumption by 8–10% and power consumption by 8–10 kWh/t of coal. (v) Replacement of old lean phase pneumatic conveyor systems by mechanical conveyor systems or by dense phase systems can save Rs 13.8 million/year.

Short term measures.

(i) Replacement of old and inefficient fans by high efficiency new fans will save Rs 5.1 million/year. (ii) Incorporation of variable speed drives for major process fans like preheater fans, fans in coolers of kilns, etc., will save Rs 2.8 million/year. (iii) Installation of capacitor banks for various auxiliary equipment to improve power factors will save Rs 9.4 million/year. (iv) Introduction of pulse energization in the control circuits of kiln ESP will save Rs 1.6 million/year. (v) Modification of the burner pipe system to reduce primary air to the kilns to improve combustion efficiency will save Rs 4.3 million/year. (vi) Replacement of old low-pressure clinker grate coolers by high-pressure coolers will improve recuperation efficiency by 6–8%, reduce energy consumption by 30 kcal/kg of clinker and save Rs 1 2 million/year. (vii) Use of excess cooling air for grate coolers in drying the coal inside coal mills can save Rs 2.3 million/year. (viii) Installation of insulating blocks as back-up for lining in calcinating zone of wet and semi-dry process kilns can result in 1–2% reduction in energy consumption and save Rs 0.2 million/year.

Environmental performance

Using the dry process, CO_2 produced per tonne of cement is 1239 kg for a coal-fired plant, 1036 kg for a natural gas plant, 964 kg for a highly efficient natural gas plant. For a plant using wet process CO_2 produced per tonne of cement is 1352 kg. (These values are for a unit of 2 mt/year production capacity).[8]

Comments

Use of natural gas in cement plants would lead to better control of pyroprocessing and, hence, to better quality of clinker It would also avoid the transport of high ash coal, save the associated cost, fuel, and prevent pollution There would, however, be a small increase in the cost due to the need for additional silicous material (e.g., clay) to compensate for the ash from coal which is absorbed in the cement clinkers [7]

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